DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
George K. Burgess, Director

BUREAU OF STANDARDS JOURNAL OF RESEARCH

January, 1929
Vol. 2, No. 1

$2.75 PER YEAR ON SUBSCRIPTION
Sold only by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C.

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1929

For a list of previous research papers appearing in Volume 1, BUREAU OF STANDARDS JOURNAL OF RESEARCH, see pages 2, 3, and 4 of cover

FIRE RESISTANCE OF HOLLOW LOAD-BEARING WALL TILE

By S. H. Ingberg and H. D. Foster

ABSTRACT

The work reported in this paper consists in the main of three series of fire tests of wall constructions built of hollow load-bearing wall tile of representative designs and clay materials.

The first tests were made on wall sections 1 foot wide and 6 feet high that were subjected to fire on one side while under working load, the main object of the tests being to determine how the fire exposure affects the individual tile units. This was found to vary with the type of clay used, hardness of burning and design of the unit, from minor cracking of a few of the units in the specimen to failure under load a little after two hours.

The second group of tests was with wall specimens 4 feet wide and 4 feet high tested exposed to fire on one side, under load or restrained within the containing frames, and were made to study the effect of changes in design of the unit, and in the constituents and preparation of the clay.

Addition of up to 2 per cent of ground burned clay (grog) to the raw clay was found to be without effect, but higher percentages increased the fire damage, apparently because of initial shrinkage cracks radiating from the grog particles. Additions of up to 15 per cent by volume of sawdust to the raw clay decreased the tendency to cracking when exposed to fire without seriously decreasing the normal strength of the tile. Finer grinding and greater amount of pugging of the raw clay increased the strength of the tile and consequently its load-carrying ability when exposed to fire.

Of modifications in the design of the unit, one with double outside shells improved the fire resistance for all but very dense tile in confining the cracking mainly to an outer thin shell. Increased shell thickness was also found to decrease the fire effects, as also fillets of up to one-fourth inch radius at the junctions of shells and webs.

The final series consisted of 167 fire-endurance tests and four fire and water tests of typical wall constructions, 71 of which were made with walls between 10 and 11 feet high and 8 to 16 feet wide. The thickness ranged from 8 to 16 inches, and plaster, stucco, or brick facing was applied on a number of the walls. The walls were subjected to constant applied loads of 70 to 120 lbs./in.^{2} during the fire test, were restrained within the containing frames, or were tested unrestrained, the latter condition being representative of walls in low buildings or the upper-story walls of higher buildings. The results are summarized as fire-resistance periods, which are determined by the time the walls sustained load under fire exposure and prevented the average temperature rise on the unexposed side from exceeding 139° C. (250° F.) or the maximum rise at any point where temperature measurements are taken from exceeding 180.6° C. (325° F.). Freedom from cracks or openings large enough to transmit flame or ignite combustible materials is also required both in fire-endurance tests and fire and water tests.

The final grouping of test results is in three classes determined by the design of the tile. Fire-resistance periods are given for 8, 12, and 16 inch walls in each class, the values varying with the thickness and design from 1¾ to 11 hours for unplastered walls and from 4 to 15 hours for walls plastered on both sides.

108591°—28——1

Periods are also given for walls assumed to have combustible members projecting into them 4 inches from the unexposed side, this being determined by the time required for temperatures high enough to ignite wood to obtain at the given depth in the wall. Fire-resistance periods for this condition ranged from 1 hour with 8-inch unplastered walls to 10 hours with 16-inch plastered walls built of tile of the designs giving the highest results.

CONTENTS

	Page
I. Introduction	16
1. Scope of tests	16
2. Acknowledgments	17
II. Tests to determine fire effects on individual units	17
1. Material	18
(*a*) Clays and manufacturing details	18
(1) Chemical analyses	20
(2) Softening point	20
(*b*) Tile	22
(1) Compressive strength and absorption	22
(2) Structure	23
(3) Expansion	23
(4) Weathering resistance	27
2. Fire tests	28
(*a*) Furnace equipment	28
(*b*) Test specimens	28
(*c*) Method of testing	28
3. Results	29
(*a*) Shales	29
(*b*) Fire clays	30
(1) Dense-burning fire clays	30
(2) Open-burning fire clays	30
(*c*) Shale and fire-clay mixture	31
(*d*) Surface clays	31
4. Summary and discussion	32
(*a*) Clay characteristics	32
(*b*) Tile characteristics	32
III. Effect of design and manufacturing details	33
1. Testing equipment	33
2. Construction of tests walls	34
3. Testing methods	34
4. Results of tests	35
(*a*) Effect of grog additions	35
(*b*) Effect of combustible filler additions	36
(1) Tests with shale tile	36
(2) Tests with fire-clay and surface-clay tile	36
(*c*) Effect of fineness of grinding of the clay	38
(1) Shale	38
(2) Fire clay	38
(*d*) Amount of pugging of the clay	39
(*e*) Design of unit	39
(*f*) Shell thickness	41
(*g*) Fillets	42

Page

IV. Fire tests of typical hollow-tile walls 42
1. Purpose 42
2. Scope of tests 42
(*a*) Types of clay and details of manufacture 43
(*b*) Design of units 45
(1) Notation 45
(2) Description of typical designs 45
(*c*) Types of construction 51
(*d*) Plaster 51
3. Program of tests 52
(*a*) Fire-endurance tests 53
(*b*) Fire and water tests 54
4. Construction of tests walls 62
(*a*) Size 62
(*b*) Restraint and loading 63
(*c*) Workmanship 63
(*d*) Mortar 67
(1) Mortar materials 68
5. Storing and aging of walls 68
6. Auxiliary tests of materials 70
(*a*) Tests of mortar and plaster 70
(*b*) Tests of individual tile units 70
(*c*) Compressive strength of masonry specimens 71
7. Description of furnace and equipment 71
(*a*) Frames for containing walls 71
(*b*) Loading apparatus 71
(*c*) Apparatus for moving walls 74
(*d*) Testing furnace 75
(1) Combustion chamber 75
(2) Burners 75
(*e*) Fire-stream apparatus 75
8. Temperature measurements 76
(*a*) Instruments 76
(*b*) Furnace temperatures 76
(*c*) Wall temperatures 76
(*d*) Method of taking and reducing observations 78
(*e*) Calibration of thermocouples 78
9. Deflection measurements 78
10. Method of testing 78
(*a*) Loading 79
(*b*) Fire exposure 79
(*c*) Observations during test 86
(*d*) Observations after test and during dismantling of the wall 86
(*e*) Compression test of masonry specimens 86
(*f*) Photographic records 86
(*g*) Fire and water test procedure 86
11. Results of fire-endurance tests 87
(*a*) Conditions of walls after fire-endurance tests 87
(*b*) Furnace temperatures 87
(*c*) Wall temperatures 91
(*d*) Temperatures of unexposed surface 91
(*e*) Test duration 98

IV. Fire tests of typical hollow-tile walls—Continued.
11. Results of fire-endurance tests—Continued. Page
(*f*) Expansion 98
(*g*) Lateral deflection 98
(*h*) Compression tests of masonry specimens 99
(*i*) Log of fire-endurance tests 101
12. Results of fire and water tests 152
(*a*) Compression tests of masonry 152
(*b*) Log of fire and water tests 152
13. Summary and discussion of results 155
(*a*) Damage to the construction 155
(1) Effect of type of clay and burning 156
(2) Effect of number of cells, webs, and units 157
(3) Effect of wall openings 157
(4) Size of unit 158
(5) Design of unit 158
(6) Effect of plaster 158
(7) Effect of load and restraint 161
(*b*) Load-carrying ability 162
(1) Type of clay 165
(2) Design 166
(3) Mortar 166
(4) Plaster 166
(5) Strength of masonry 167
(*c*) Expansion and deflection 167
(*d*) Repair of fire-damaged walls 168
(*e*) Fire and water tests 169
(*f*) Temperature transmission 170
(1) Shell thickness and clay 171
(2) Workmanship 171
(3) Design 171
(4) Effect of plaster 172
(5) Seasoning conditions 172
(6) Temperature rise at single locations 173
(7) Temperature rise after fire test 173
(8) Temperature under large pads and at cracks 174
(9) Flame passage 175
14. Fire-resistance periods of hollow-tile walls 177
(*a*) Method of derivation 177
(*b*) Table of fire-resistance periods 178
(*c*) Summary of fire-resistance periods 179
V. Application of results to fire conditions in buildings 188
1. Intensity and duration of building fires 188
2. Fire-exposure conditions for walls 190
(*a*) Exterior exposure 190
(*b*) Interior exposure 190
(1) Interior walls or partitions 190
(2) Exterior walls 190
3. Significance of fire-resistance classifications 191
4. Fire damage 192
5. Fire resistance in relation to other properties 192
Appendix A 324
Appendix B 326
Appendix C 330
Appendix D 334

TABLES

		Page
1.	Chemical analysis of clays	21
2.	Softening points of hollow-tile clays	22
3.	(*a*) Compressive strength and absorption of hollow tile used in preliminary fire tests	24
3.	(*b*) Summary of physical and chemical properties of hollow-tile material	26
4.	Test durations of walls of tile containing grog	35
5.	Test durations of walls of shale tile containing combustible filler	36
6.	Strength and absorption of tile containing combustible filler	37
7.	Strength and absorption of tile in the fineness of grinding series	38
8.	Strength and absorption of tile in the pugging series	39
9.	Program of fire-endurance tests	55
10.	Program of fire and water tests	62
11.	Construction and strength data for large walls	64
12.	Analysis of Portland cement	68
13.	Analysis of gypsum plaster	68
14.	Compressive strength and absorption of hollow tile and brick in main series of fire tests	72
15.	Test conditions	80
16.	Lateral deflections of large walls	89
17.	Temperature data from fire-endurance tests	92
18.	Walls whose fire-resistance periods were determined by load-carrying ability	163
19.	Ultimate fire-resistance periods of hollow-tile walls	180
20.	Summary of fire-resistance periods	186

FIGURES

		Page
1	Expansion curves of samples of shale tile. For letter designation, see text page 18	26
2.	Expansion curves of samples of fire-clay tile. For letter designation, see text, page 18	27
3.	Expansion curves of samples of surface-clay tile. For letter designation, see text, page 18	27
4.	Front of original testing furnace showing specimen in position and loaded preparatory to fire test—facing	28
5.	Side and rear of original testing furnace showing temperature-measuring apparatus and method of loading test specimen—facing	29
6.	Typical test specimens before fire exposure—facing	28
7.	Exposed side of typical test specimens after fire exposure—facing	29
8.	Storage of small walls while aging them before fire test—facing	34
9.	Small test furnace showing wall prepared for test—facing	34
10.	Design of 8 by 12 by 12 inch experimental unit with curved transverse shells and webs	40
11.	(A) Original design of double shell unit showing usual place of fracture of webs when exposed to fire. (B) Improved design of double shell unit showing usual place of fracture of webs when exposed to fire	41
12a.	Some typical wall constructions	47
12b.	Some typical wall constructions	48
12c.	Some typical wall constructions	49
13.	Design of hollow tile used in fire-endurance tests	50
14.	Plan layout of large furnace and related equipment	69

Page

15. Section through large testing furnace 74
16. Comparison of temperatures measured near the same point with couples protected by the standard porcelain tube and by iron tube with closed end 77
17. Condition of a cotton pad and an excelsior-filled box after being in contact with the unexposed side of a wall during fire exposure ..... facing.. 78
18. Average furnace temperatures compared with standard furnace temperatures 88
19a. Typical expansion curves of small walls 99
19b, 19c. Typical deflection curves of large walls 100, 101
20. Ultimate fire-resistance periods of hollow-tile walls 102
21. A. Exposed side of wall No. 1 after fire exposure of 6 hours. B. Exposed side of wall No. 7 after fire exposure of 6 hours. C. Unexposed side of wall No. 3 after fire exposure of 2 hours 51 minutes. D. Exposed side of wall No. 3 after fire exposure of 2 hours 51 minutes ..... facing.. 102
22. A. Unexposed side of north half of wall No. 4 after fire exposure of 2 hours 17 minutes. B. Exposed side of north half of wall No. 4 after fire exposure of 2 hours 17 minutes. C. Exposed side of north half of wall No. 5 before fire exposure. This wall was obtained by repairing wall No. 4. D. Exposed side of north half of wall No. 5 after fire exposure of 5 hours 7 minutes. facing.. 103
23. A. Unexposed side of wall No. 6 after fire exposure of 2 hours 53 minutes. B. Exposed side of wall No. 6 after fire exposure of 2 hours 53 minutes ..... facing.. 102
24. A. Exposed side of wall No. 9 after fire exposure of 5 hours 30 minutes. B. Exposed side of wall No. 10 after fire exposure of 5 hours 30 minutes. C. Exposed side of wall No. 15 after fire exposure of 5 hours 30 minutes. D. Exposed side of wall No. 16 after fire exposure of 5 hours 30 minutes ..... facing.. 103
25. A. Unexposed side of wall No. 11 after fire exposure of 1 hour 30 minutes. B. Exposed side of wall No. 11 after fire exposure of 1 hour 30 minutes. C. Exposed side of wall No. 14 after fire exposure of 6 hours 6 minutes, and after removing furring. D. Exposed side of wall No. 20 after fire exposure of 1 hour 30 minutes. E. Exposed side of wall No. 23 after fire exposure of 1 hour 30 minutes. F. Exposed side of wall No. 27 after fire exposure of 6 hours ..... facing.. 102
26. A. Unexposed side of wall No. 26 after fire exposure of 3 hours 12 minutes. B. Exposed side of wall No. 26 after fire exposure of 3 hours 12 minutes. C. Exposed side of wall No. 28 after fire exposure of 3 hours 56 minutes. D. Exposed side of wall No. 29 after fire exposure of 4 hours 43 minutes. E. Unexposed side of wall No. 30 after fire exposure of 3 hours 36 minutes. F. Exposed side of wall No. 30 after fire exposure of 3 hours 36 minutes ..... facing.. 103
27. A. Unexposed side of wall No. 35 after fire exposure of 45 minutes. B. Exposed side of wall No. 35 after fire exposure of 45 minutes. C. Exposed side of wall No. 36 after fire exposure of 6 hours. D. Exposed side of wall No. 38 after fire exposure of 3 hours 31 minutes ..... facing.. 102
28. A. Unexposed side of wall No. 42 after fire exposure of 4 hours 12 minutes. B. Exposed side of wall No. 42 after fire exposure of 4 hours 12 minutes ..... facing.. 103

Page

29. A. Exposed side of wall No. 47 after fire exposure of 1 hour 30 minutes. B. Exposed side of wall No. 50 after fire exposure of 1 hour 30 minutes. C. Exposed side of wall No. 48 after fire exposure of 1 hour 30 minutes. D. Exposed side of wall No. 48 after removing plaster. E. Exposed side of wall No. 51 after fire exposure of 1 hour 30 minutes. F. Exposed side of wall No. 52 after fire exposure of 1 hour 30 minutes ---- facing -- 118

30. A. Exposed side of wall No. 53 after fire exposure of 1 hour 30 minutes B. Exposed side of wall No. 54 after fire exposure of 1 hour 30 minutes. C. Exposed side of wall No. 55 after fire exposure of 1 hour 30 minutes. D. Exposed side of wall No. 56 after fire exposure of 1 hour 30 minutes. E. Exposed side of wall No. 58 after fire exposure of 1 hour 30 minutes. F. Exposed side of wall No. 59 after fire exposure of 1 hour 30 minutes ---- facing -- 119

31. A. Unexposed side of wall No. 60 after fire exposure of 4 hours 25 minutes. B. Exposed side of wall No. 60 after fire exposure of 4 hours 25 minutes. C. Unexposed side of wall No. 61 after fire exposure of 3 hours 21 minutes. D. Exposed side of wall No. 61 after fire exposure of 3 hours 21 minutes ---- facing -- 118

32. A. Exposed side of wall No. 62 after fire exposure of 2 hours 22 minutes. B. Exposed side of wall No. 63 after fire exposure of 1 hour 38 minutes. C. Unexposed side of wall No. 64 after fire exposure of 2 hours 42 minutes. D. Exposed side of wall No. 64 after fire exposure of 2 hours 42 minutes. E. Unexposed side of wall No. 65 after fire exposure of 6 hours. F. Exposed side of wall No. 65 after fire exposure of 6 hours ---- facing -- 119

33. A. Unexposed side of wall No. 67 at end of fire exposure of 6 hours. B. Exposed side of wall No. 67 after fire exposure of 6 hours ---- facing -- 118

34. A. Exposed side of wall No. 68 after fire exposure of 6 hours. B. Exposed side of wall No. 68 after removal of plaster ---- facing -- 119

35. A. Exposed side of wall No. 69 after fire exposure of 6 hours. B. Exposed side of wall No. 74 after fire exposure of 3 hours 1 minute. C. Exposed side of wall No. 76 after fire exposure of 6 hours ---- facing -- 118

36. A. Unexposed side of wall No. 79 after fire exposure of 2 hours. B. Exposed side of wall No. 79 after fire exposure of 2 hours. C. Unexposed side of wall No. 80 after fire exposure of 2 hours. D. Exposed side of wall No. 80 after fire exposure of 2 hours ---- facing -- 119

37. A. Exposed side of wall No. 81 after fire exposure of 4 hours 10 minutes. B. Exposed side of wall No. 82 after fire exposure of 4 hours 10 minutes. C. Exposed side of wall No. 83 after fire exposure of 1 hour 30 minutes. D. Exposed side of wall No. 84 after fire exposure of 1 hour 30 minutes ---- facing -- 128

38. A. Exposed side of wall No. 87 after fire exposure of 3 hours 30 minutes. B. Exposed side of wall No. 88 after fire exposure of 3 hours 30 minutes. C. Exposed side of wall No. 92 after fire exposure of 1 hour 5 minutes. D. Exposed side of wall No. 94 after fire exposure of 2 hours 42 minutes ---- facing -- 129

39. A. Exposed side of wall No. 89 after fire exposure of 6 hours. B. Exposed side of wall No. 89 after removing some of loosened outer shells. C. Exposed side of wall No. 90 after fire exposure of 6 hours. D. Exposed side of wall No. 90 after removing plaster ---- facing -- 128

Page

40. A. Exposed side of wall No. 95 after fire exposure of 4 hours 7 minutes. B. Exposed side of wall No. 96 after fire exposure of 6 hours. C. Exposed side of wall No. 97 after fire exposure of 4 hours 7 minutes. D. Exposed side of wall No. 98 after fire exposure of 6 hours ---- facing -- 129
41. A. Exposed side of wall No. 101 after fire exposure of 6 hours. B. Exposed side of wall No. 103 after fire exposure of 6 hours. C. Exposed side of wall No. 107 after fire exposure of 3 hours 23 minutes. D. Exposed side of wall No. 109 after fire exposure of 4 hours 45 minutes ---- facing -- 128
42. A. Exposed side of wall No. 105 after fire exposure of 6 hours. B. Exposed side of wall No. 106 after fire exposure of 6 hours. C. Exposed side of wall No. 110 after fire exposure of 4 hours 2 minutes, and removal of plaster. D. Exposed side of wall No. 111 after fire exposure of 4 hours 2 minutes, and removal of plaster ---- facing -- 129
43. A. Unexposed side of wall No. 112 after fire exposure of 5 hours 31 minutes. B. Exposed side of wall No. 112 after fire exposure of 5 hours 31 minutes, and removal of plaster. C. Unexposed side of wall No. 113 after fire exposure of 5 hours 31 minutes. D. Exposed side of wall No. 113 after fire exposure of 5 hours 31 minutes, and removal of plaster ---- facing -- 128
44. A. Unexposed side of wall No. 114 after fire exposure of 6 hours. B. Exposed side of wall No. 114 after fire exposure of 6 hours. C. Exposed side of wall No. 115 after fire exposure of 3 hours. D. Exposed side of wall No. 115 after removing loosened shells. E. Exposed side of wall No. 116 after fire exposure of 6 hours. F. Exposed side of wall No. 117 after fire exposure of 3 hours ---- facing -- 129
45. A. Unexposed side of wall No. 119 after fire exposure of 4 hours 10 minutes. B. Exposed side of wall No. 119 after fire exposure of 4 hours 10 minutes. C. Unexposed side of wall No. 121 after fire exposure of 6 hours. D. Exposed side of wall No. 121 after fire exposure of 6 hours. E. Unexposed side of wall No. 122 after fire exposure of 3 hours. F. Exposed side of wall No. 122 after fire exposure of 3 hours ---- facing -- 138
46. A. Exposed side of wall No. 124 after fire exposure of 5 hours. B. Exposed side of wall No. 123 after fire exposure of 2 hours 22 minutes. C. Exposed side of wall No. 125 after fire exposure of 8 hours 33 minutes. D. Exposed side of wall No. 126 after fire exposure of 10 hours 42 minutes ---- facing -- 139
47. A. Exposed side of wall No. 130 after fire exposure of 6 hours. B. Exposed side of wall No. 130 after removing loosened shells. C. Exposed side of wall No. 134 after fire exposure of 3 hours. D. Exposed side of wall No. 134 after removing loosened shells. E. Unexposed side of wall No. 139 after fire exposure of 5 hours 32 minutes. F. Exposed side of wall No. 140 after fire exposure of 8 hours 15 minutes ---- facing -- 138
48. A. Exposed side of wall No. 141 after fire exposure of 4 hours. B. Exposed side of wall No. 142 after fire exposure of 4 hours. C. Exposed side of wall No. 143 after fire exposure of 4 hours. D. Exposed side of wall No. 144 after fire exposure of 2 hours ---- facing -- 139

Page

49. A. Unexposed side of wall No. 146 after fire exposure of 6 hours. B. Exposed side of wall No. 146 after fire exposure of 6 hours. C. Unexposed side of wall No. 147 after fire exposure of 6 hours. D. Exposed side of wall No. 147 after fire exposure of 6 hours ---- facing-- 138
50. A. Exposed side of wall No. 148 after fire exposure of 5 hours 11 minutes. B. Unexposed side of wall No. 158 after fire exposure of 12 hours 33 minutes. C. Exposed side of wall No. 158 after fire exposure of 12 hours 33 minutes ---- facing-- 139
51. A. Unexposed side of wall No. 150 after fire exposure of 18 hours 10 minutes. B. Exposed side of wall No. 150 after fire exposure of 18 hours 10 minutes. C. Exposed side of wall No. 149 after fire exposure of 13 hours 48 minutes. D. Exposed side of wall No. 157 after fire exposure of 8 hours 45 minutes. E. Exposed side of wall No. 154 after fire exposure of 9 hours 24 minutes. F. Exposed side of wall No. 160 after fire exposure of 10 hours 45 minutes ---- facing-- 138
52. A. Exposed side of wall No. 133a after fire exposure of 3 hours 38 minutes. B. Exposed side of wall No. 160a after fire exposure of 9 hours 3 minutes. C. Exposed side of wall No. 161 after fire exposure of 14 hours 16 minutes. D. Exposed side of wall No. 163 after fire exposure of 12 hours 45 minutes. E. Unexposed side of wall No. 162 after fire exposure of 7 hours 1 minute. F. Exposed side of wall No. 162 after fire exposure of 7 hours 1 minute ---- facing-- 139
53. A. Exposed side of wall No. 165 at end of one hour of fire exposure. B. Exposed side of wall No. 165 after application of water_facing-- 152
54. A. Exposed side of wall No. 166 after one hour of fire exposure. B. Exposed side of wall No. 166 after water application_facing-- 153
55. A. Exposed side of wall No. 168 after one hour of fire exposure. B. Exposed side of wall No. 168 after water application_facing-- 154
56. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell shale tile, source *d*, test No. 1 ---- 193
57. Furnace and wall temperatures, 8-inch unplastered walls of end-construction 6-cell shale tile, source *d*, tests Nos. 2 and 3 ---- 194
58. Furnace and wall temperatures, 8-inch unplastered walls of end-construction 6-cell shale tile, source *d*, tests Nos. 4 and 6 ---- 195
59. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell shale tile, source *a–1*, test No. 7 ---- 196
60. Furnace and wall temperatures, 8-inch wall of end construction 6-cell shale tile, source *d*, set on side, gypsum plaster on fire side, test No. 8 ---- 197
61. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell shale tile, source *d*, gypsum plaster both sides, test No. 9 ---- 198
62. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell shale tile, source *d*, furred on fire side, gypsum plaster both sides, test No. 13 ---- 199
63. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell shale tile, source *d*, furred on fire side, gypsum plaster both sides, test No. 14 ---- 200
64. Furnace and wall temperatures, 8-inch wall of end-construction double-shell shale tile, source *d*, gypsum plaster both sides, test No. 15 ---- 201

Page

65. Furnace and wall temperatures, 8-inch unplastered wall of 8 by 5-inch side-construction 3-cell shale tile, source *c*, test No. 17; 8-inch unplastered wall of 8 by 5 inch side-construction 2-cell shale tile, source *d–2*, test No. 18 202
66. Furnace and wall temperatures, 8-inch unplastered walls of side-construction interlocking shale tile, source *d–1*, tests Nos. 19 and 20 203
67. Furnace and wall temperatures, 8-inch unplastered wall of side-construction interlocking shale tile, source *d–1*, test No. 21 204
68. Furnace and wall temperatures, 8-inch unplastered walls of side construction, H-shaped shale tile, source *c–1*, tests Nos. 22 and 23 205
69. Furnace and wall temperatures, 8-inch unplastered wall of side-construction cube shale tile, source *d*, test No. 24 206
70. Furnace and wall temperatures, 8-inch wall of side-construction cube shale tile, source *d*, gypsum plaster fire side, test No. 25 207
71. Furnace and wall temperatures, 8-inch unplastered wall of 8 by 8 inch side-construction shale tile, source *a*, test No. 26 208
72. Furnace and wall temperatures, 8-inch wall of 8 by 8 inch side-construction shale tile, source *a*, gypsum plaster fire side, test No. 27 209
73. Furnace and wall temperatures, 8-inch unplastered wall of 8 by 3½ inch side-construction 3-cell shale tile, source *d–3*, test No. 28 210
74. Furnace and wall temperatures, 8-inch wall of 8 by 3½ inch side-construction 3-cell shale tile, source *d–3*, gypsum plaster fire side, test No. 29 211
75. Furnace and wall temperatures, 8-inch wall of 8 by 5 inch side-construction double-shell shale tile, source *d–3*, gypsum plaster fire side, test No. 30 212
76. Furnace and wall temperatures, 8-inch wall of 8 by 5 inch side-construction, double-shell shale tile, source *d–3*, gypsum plaster fire side, test No. 31 213
77. Furnace and wall temperatures, 8-inch unplastered walls of end-construction 6-cell surface-clay tile, source *j*, tests Nos. 32 and 33 214
78. Furnace and wall temperatures, 8-inch wall of end-construction 9-cell surface-clay tile, source *j*, gypsum plaster fire side, test No. 36 215
79. Furnace and wall temperatures, 8-inch wall of end-construction 9-cell surface-clay tile, source *j*, cement plaster both sides, test No. 37 216
80. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 9-cell surface-clay tile, source *j*, test No. 38 217
81. Furnace and wall temperatures, 8-inch wall of end-construction 9-cell surface-clay tile, source *j*, gypsum plaster fire side, test No. 39 218
82. Furnace and wall temperatures, 8-inch unplastered walls of end-construction 6-cell surface-clay tile, source *r*, tests Nos. 40 and 41 219
83. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell xxx surface-clay tile, source *k*, test No. 42 220
84. Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell xxx surface-clay tile, source *k*, test No. 43 221
85. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell xxx surface-clay tile, source *k*, test No. 44 222
86. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell xxx surface-clay tile, source *k*, gypsum plaster fire side, test No. 45 223

Page

87. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell xxx surface-clay tile, source *k*, cement plaster both sides, test No. 46 ---- 224
88. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell xxx surface-clay tile, source *k*, test No. 47; 8-inch wall of end-construction 6-cell xxx surface-clay tile, source *k*, cement plaster both sides, test No. 48; 8-inch wall of end-construction 6-cell xxx surface-clay tile, source *k*, gypsum plaster both sides, test No. 49; 8-inch wall of end-construction 6-cell xxx surface-clay tile, source *k*, lime plaster both sides, test No. 50 ---- 225
89. Furnace and wall temperatures, 8-inch walls of end-construction 6-cell xxx surface-clay tile, source *k*, cement lime plaster fire side, tests Nos. 51, 52, and 53; 8-inch walls of end-construction 6-cell xxx surface-clay tile, source *k*, lime plaster fire side, tests Nos. 54 and 55 -- 226
90. Furnace and wall temperatures, 8-inch walls of end-construction 6-cell xxx surface-clay tile, source *k*, cement plaster fire side, tests Nos. 56 and 57; 8-inch walls of end-construction 6-cell xxx surface-clay tile, source *k*, gypsum plaster fire side, tests Nos. 58 and 59 - 227
91. Furnace and wall temperatures, 8-inch unplastered wall of side-construction interlocking surface-clay tile, source *p–1*, test No. 60 - 228
92. Furnace and wall temperatures, 8-inch unplastered wall of side-construction 8 by 5 inch 3-cell surface-clay tile, source *o–1*, test No. 61; 8-inch unplastered wall of side-construction 8 by 5 inch 2-cell surface-clay tile, source *k–1*, test No. 62 ---- 230
93. Furnace and wall temperatures, 8-inch unplastered wall of side-construction 8 by 5 inch 2-cell surface clay tile, source *k–3*, test No. 63; 8-inch unplastered wall of side-construction 8 by 5 inch 6-cell surface-clay tile, source *k–2*, test No. 64 ---- 231
94. Furnace and wall temperatures, 8-inch unplastered walls of side-construction interlocking surface-clay tile, source *r*, tests Nos. 65 and 66 ---- 232
95. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell fire-clay tile, source *n*, test No. 67 ---- 233
96. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell fire-clay tile, source *n*, gypsum plaster both sides, test No. 68 -
97. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell fire-clay tile, source *n*, test No. 69 ---- 234
98. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell fire-clay tile source *n*, gypsum plaster both sides, test No. 70 - 235
99. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell fire-clay tile, source *n*, test No. 71 ---- 236
100. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell fire-clay tile, source *n*, gypsum plastered both sides, test No. 72 ---- 237
101. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell fire-clay tile, source *l*, test No. 73 ---- 238
102. Furnace and wall temperatures, 8-inch unplastered walls of end-construction 6-cell fire-clay tile, source *l*, tests Nos. 74 and 75 ---- 239
103. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell fire-clay tile, source *l*, test No. 76 ---- 240
104. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell fire-clay tile, source *l*, gypsum plaster fire side, test No. 77 -- 241

Page

105. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell fire-clay tile, source *l*, set on side, test No. 79; 8-inch wall of end-construction, 6-cell fire-clay tile, source *l*, set on side, gypsum plaster both sides, test No. 80 242
106. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell fire-clay tile, source *l*, set on side, test No. 81 .. 243
107. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell fire-clay tile, source *l*, set on side, gypsum plaster both sides, test No. 82 244
108. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell xxx fire-clay tile, source *m*, test No. 83; 8-inch wall of end-construction 6-cell xxx fire-clay tile, source *m*, gypsum plaster both sides, test No. 84; 8-inch unplastered wall of end-construction 6-cell shale tile, source *d*, test No. 11; 8-inch wall of end-construction 6-cell shale tile, source *d*, gypsum plaster both sides, test No. 12 245
109. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell xxx fire-clay tile, source *m*, gypsum plaster fire side, test No. 85 246
110. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell xxx fire-clay tile, source *m*, gypsum plaster both sides, test No. 86 247
111. Furnace and wall temperatures, 8-inch wall of end-construction 6-cell xxx fire-clay tile, source *m*, gypsum plaster both sides, test No. 87 248
112. Furnace and wall temperatures, 8-inch wall, furred on fire side, of end-construction 6-cell xxx fire-clay tile, source *m*, gypsum plaster fire side, test No. 88 249
113. Furnace and wall temperatures, 8-inch unplastered wall of end-construction double-shell fire-clay tile, source *m*, test No. 89 250
114. Furnace and wall temperatures, 8-inch wall of end-construction double-shell fire-clay tile, source *m*, gypsum plaster both sides, test No. 90 251
115. Furnace and wall temperatures, 8-inch unplastered wall of end-construction double-shell fire-clay tile, source *m*, test No. 91 252
116. Furnace and wall temperatures, 8-inch unplastered walls of end-construction double-shell fire-clay tile, source *m*, tests Nos. 92 and 93 253
117. Furnace and wall temperatures, 8-inch unplastered wall of side-construction 8 by 5 inch 3-cell fire-clay tile, source *h*, test No. 94; 8-inch unplastered wall of side-construction 8 by 5 inch 3-cell fire-clay tile, source *l–2*, test No. 99 254
118. Furnace and wall temperatures, 8-inch unplastered wall of side-construction 8 by 5 inch 3-cell fire-clay tile, source *m*, test No. 95 255
119. Furnace and wall temperatures, 8-inch wall of side-construction 8 by 5 inch 3-cell fire-clay tile, source *m*, gypsum plaster both sides, test No. 96 256
120. Furnace and wall temperatures, 8-inch unplastered wall of side-construction 8 by 5 inch 2-cell fire-clay tile, source *m*, test No. 97 257
121. Furnace and wall temperatures of 8-inch wall of side-construction 8 by 5 inch 2-cell fire-clay tile, source *m*, gypsum plaster both sides, test No. 98 258

Page

122. Furnace and wall temperatures, 8-inch unplastered walls of side-construction interlocking fire-clay tile, source *l–1*, tests Nos. 101 and 102 259
123. Furnace and wall temperatures, 8-inch unplastered walls of side-construction H-shaped fire-clay tile, source *l*, tests Nos. 103 and 104 260
124. Furnace and wall temperatures, 8-inch unplastered wall of side-construction H-shaped fire-clay tile, source *l*, test No. 105 261
125. Furnace and wall temperatures, 8-inch wall of side-construction H-shaped fire-clay tile, source *l*, gypsum plaster both sides, test No. 106 262
126. Furnace and wall temperatures, 8-inch unplastered wall of side-construction cube fire-clay tile, source *f*, test No. 107 263
127. Furnace and wall temperatures, 8-inch wall of side-construction cube fire-clay tile, source *f*, gypsum plaster both sides, test No. 108 264
128. Furnace and wall temperatures, 8-inch wall of side-construction cube fire-clay tile, source *f*, set on end, gypsum plaster both sides, test No. 109 265
129. Furnace and wall temperatures, 10-inch wall of end-construction 3¾ by 12 inch 3-cell fire-clay tile, source *l*, set on side, gypsum plaster fire side, cement plaster unexposed side, test No. 110 266
130. Furnace and wall temperatures, 10-inch wall of side-construction 3¾ by 5 inch fire-clay tile, source *l*, gypsum plaster fire side, cement plaster unexposed side, test No. 111 267
131. Furnace and wall temperatures, brick-faced 8-inch wall backed with side-construction 3¾ by 5 inch 1-cell fire-clay tile, source *m*, gypsum plaster fire side, test No. 112 268
132. Furnace and wall temperatures, brick-faced 8-inch wall backed with end-construction 3-cell xxx fire-clay tile, source *m*, gypsum plaster fire side, test No. 113 269
133. Furnace and wall temperatures, 12-inch unplastered wall of end-construction 6-cell shale tile, source *d*, test No. 114 270
134. Furnace and wall temperatures, 12-inch unplastered wall of end-construction 6-cell shale tile, source *d*, test No. 115 271
135. Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end-construction 6-cell and 3-cell shale tile, source *d*, test No. 116 272
136. Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end-construction 6-cell and 3-cell shale tile, source *d*, test No. 117 273
137. Furnace and wall temperatures, 12-inch unplastered wall of side-construction interlocking shale tile, source *d–1*, test No. 118 274
138. Furnace and wall temperatures, 12-inch unplastered wall of end-construction 6-cell surface-clay tile, source *j*, test No. 119 275
139. Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end-construction 9-cell and 3-cell surface-clay tile, source *j*, test No. 120 276
140. Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end-construction 6-cell and 3-cell surface-clay tile, source *j*, test No. 121 277
141. Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end-construction 6-cell and 3-cell surface-clay tile, source *j*, test No. 122 278

Page

142. Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end-construction 9-cell and 3-cell surface-clay tile, source *j*, test No. 123 279
143. Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end-construction xxx 6-cell and 3-cell surface-clay tile, source *k*, test No. 124 280
144. Furnace and wall temperatures, 12-inch unplastered wall of side-construction interlocking surface-clay tile, source *p–1*, test No. 125 281
145. Furnace and wall temperatures, 12-inch unplastered wall of side-construction interlocking surface-clay tile, source *p–1*, dried to constant weight, test No. 125A 282
146. Furnace and wall temperatures, 12-inch wall of side-construction interlocking surface-clay tile, source *p–1*, gypsum plaster both sides, test No. 126 283
147. Furnace and wall temperatures, 12-inch unplastered wall of side-construction interlocking surface-clay tile, source *p–1*, test No. 127 284
148. Furnace and wall temperatures, 12-inch unplastered wall of side-construction interlocking surface-clay tile, source *p–1*, test No. 128 285
149. Furnace and wall temperatures, 12-inch wall of side-construction interlocking surface-clay tile, source *p–1*, gypsum plaster both sides, test No. 129 286
150. Furnace and wall temperatures, 12-inch unplastered wall of end-construction 6-cell fire-clay tile, source *l*, test No. 130 287
151. Furnace and wall temperatures, 12-inch unplastered wall of end-construction 6-cell fire-clay tile, source *l*, test No. 131 288
152. Furnace and wall temperatures, 12-inch unplastered wall of end-construction 6-cell fire-clay tile, source *l*, test No. 132 289
153. Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end-construction 6-cell and 3-cell fire-clay tile, source *l*, test No. 133 290
154. Furnace and wall temperatures, 8-inch unplastered wall of end-construction 6-cell fire-clay tile, source *l*, dried to constant weight, test No. 73A; 2-unit 12-inch unplastered wall of end-construction 6-cell and 3-cell fire-clay tile, source *l*, dried to constant weight, test No. 133A 291
155. Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end-construction 6-cell and 3-cell fire-clay tile, source *l*, test No. 134 292
156. Furnace and wall temperatures, 12-inch unplastered wall of end-construction 9-cell fire-clay tile, source *n*, test No. 135 293
157. Furnace and wall temperatures, 12-inch wall of end-construction 9-cell fire-clay tile, source *n*, gypsum plaster both sides, test No. 136 294
158. Furnace and wall temperatures, 12-inch unplastered wall of side-construction H-shaped fire-clay tile, source *l*, test No. 137 295
159. Furnace and wall temperatures, 12-inch wall of side-construction H-shaped fire-clay tile, source *l*, gypsum plaster both sides, test No. 138 296
160. Furnace and wall temperatures, 12-inch unplastered wall of side-construction cube fire-clay tile, source *f*, test No. 139 297

Page

161. Furnace and wall temperatures, 12-inch wall of side-construction cube fire-clay tile, source *f*, gypsum plaster both sides, test No. 140 298
162. Furnace and wall temperatures, brick-faced 12-inch unplastered wall backed with "header backer" fire-clay tile, source *p*, test No. 141 299
163. Furnace and wall temperatures, brick-faced 12-inch wall of "header backer" fire-clay tile, source *p*, gypsum plaster fire side, test No. 142 300
164. Furnace and wall temperatures, brick-faced 12-inch unplastered wall of "header backer" fire-clay tile, source *p*, test No. 143 301
165. Furnace and wall temperatures, brick-faced 12-inch wall backed with "header backer" fire-clay tile, source *p*, gypsum plaster fire side, test No. 144; 12-inch wall of "header backer" fire-clay tile, source *p*, gypsum plaster fire side, test No. 145 302
166. Furnace and wall temperatures, brick-faced 12-inch wall backed with side-construction 1-cell and 2-cell fire-clay tile, source *m*, gypsum plaster fire side, test No. 146 303
167. Furnace and wall temperatures, brick-faced 12-inch wall backed with end-construction "xxx" fire-clay tile, source *m*; gypsum plaster fire side, test No. 147 304
168. Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of end-construction 6-cell and 3-cell shale tile, source *d*, test No. 148 305
169. Furnace and wall temperatures, 16-inch unplastered wall of side-construction interlocking surface-clay tile, source *p–1*, test No. 149 306
170. Furnace and wall temperatures, 16-inch wall of side-construction interlocking surface-clay tile, source *p–1*, test No. 150 307
171. Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of end-construction 6-cell and 3-cell fire-clay tile, source *l*, test No. 151 308
172. Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of end-construction 6-cell and 3-cell fire-clay tile, source *l*, test No. 152 309
173. Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of end-construction 6-cell and 3-cell fire-clay tile, source *l*, test No. 153 310
174. Furnace and wall temperatures, 2 and 3 unit 16-inch wall of end-construction 6-cell and 3-cell fire-clay tile, source *l*, gypsum plaster both sides, test No. 154 311
175. Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of side-construction 8 by 5 inch 2-cell and 3¾ by 5 inch 1-cell fire-clay tile, source *m*, test No. 155 312
176. Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of side-construction 8 by 5 inch 3-cell and 3¾ by 5 inch 1-cell fire-clay tile, source *m*, test No. 156 313
177. Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of side-construction 8 by 5 inch 3-cell and 3¾ by 5 inch 1-cell fire-clay tile, source *m*, test No. 157 314
178. Furnace and wall temperatures, 2 and 3 unit 16-inch wall of side-construction 8 by 5 inch 3-cell and 3¾ by 5 inch 1-cell fire-clay tile, source *m*, gypsum plaster both sides, test No. 158 315
179. Furnace and wall temperatures, 16-inch unplastered wall of side-construction H-shaped fire-clay tile, source *l*, test No. 159 316

Page

180. Furnace and wall temperatures, 16-inch unplastered wall of side-construction H-shaped fire-clay tile, source *l*, test No. 160 317
181. Furnace and wall temperatures, 16-inch unplastered wall of side-construction H-shaped fire-clay tile, source *l*, dried to constant weight, test No. 160A 318
182. Furnace and wall temperatures, 16-inch wall of side-construction H-shaped fire-clay tile, source *l*, gypsum plaster both sides, test No. 161 319
183. Furnace and wall temperatures, 16-inch unplastered wall of side-construction cube fire-clay tile, source *f*, test No. 162 320
184. Furnace and wall temperatures, 16-inch wall of side-construction cube fire-clay tile, source *f*, gypsum plaster both sides, test No. 163 .. 321
185. Furnace and wall temperatures, 16-inch brick-faced wall backed with "header backer" fire-clay tile, source *p*, gypsum plaster fire side, test No. 164 322
186. Furnace temperatures, fire and water tests Nos. 165, 166, 167, and 168 . 323
187. Time-temperature curve 331

I. INTRODUCTION

Although clay tile has been used in this country for about 50 years in floor arches, partitions, and protections for structural members, it has only within the past 20 years been extensively applied for load-bearing purposes in walls. The safe and economical application of this material, as of other masonry materials, requires knowledge of its strength and fire resistance under conditions imposed by severe fires. Prior to the initiation of the work herein reported, only a few tile walls had been tested under fire-exposure conditions, and these mainly of partition tile.[1] The effects from actual fires in buildings also give little quantitative information because of the unknown and variable severity of the fires.

In 1920 a cooperative arrangement with the Hollow Building Tile Association was concluded for conducting fire tests of load-bearing tile, the first tests being made in 1921 and all tests completed in February, 1927.

1. SCOPE OF TESTS

The initial work consisted of fire tests of small wall sections mainly to determine the fire effects on the individual tile units, the tests being made as described in Section II of this report, on tile from typical clays and sources. In connection with these, as with later tests, strength, absorption, and other auxiliary tests were made of indivudual tiles, which have been reported in part in connection with the formulation of specifications.[2]

[1] "Tests of fireproof partitions by the New York department of buildings," Engineering News, **46**, No. 26, pp. 482–486, Dec. 26, 1901, describes fire tests of two hollow and three solid clay-tile partitions.

Red Book No. 99 of the British Fire Prevention Committee describes tests of 2½-inch porous tile partition made Aug. 16, 1905.

The Fire-Resistive Properties of Various Building Materials, Bulletin No. 370, U. S. Geological Survey, pp. 81–84; 1909, describes test of one 5-inch tile partition.

[2] "Strength, absorption, and freezing resistance of hollow building tile," Jr. Am. Cer. Soc., **7**, No. 3, pp. 189–199; March, 1924. Proc. Am. Soc. for Testing Materials, **24**, Pt. I, pp. 411–422, 1924, and **26**, Pt. I, pp. 285–287, 1926.

The second part consisted of 10 series of fire tests mainly on walls 4 feet square to determine effects of certain manufacturing details, design of units, and methods of application in the wall, and is treated in Section III.

The concluding, or main, series of tests included fire-endurance tests and fire and water tests of walls to determine the fire-resistance classification of the full range of the product as it concerns design of the units, types of clay, and conditions of application in buildings.

The results of all fire tests made are reported herein with the exception of those from some tests in the initial group and one in the main series, where, as later noted, specimens or testing methods were deemed at fault.

2. ACKNOWLEDGMENTS

Acknowledgments for helpful interest and cooperation are due to E. R. Sturtevant, former secretary of the Hollow Building Tile Association, and to his successor, J. S. Sleeper. Contact with this association in planning the work was had through their Standards Committee, of which H. R. Straight and J. T. Howington have served as chairmen.

The hollow tile for the tests was supplied by members of the association. The face brick was supplied by the Hydraulic Pressed Brick Co. The mortar materials and labor for building the walls and conducting the tests were contributed by the Bureau of Standards.

The technical men engaged on the work were appointed by the Director of the Bureau of Standards, some being from the bureau's regular staff and others accredited to the Hollow Building Tile Association as research associate or aid under the regulations governing cooperative research.[3] The authors participated in the work from the beginning. Acknowledgments are due to several men in the fire-resistance section of the Bureau of Standards for assistance in conducting the tests, and particularly to Gale Murphy for reducing the temperature data and preparing the plots and other illustrations for this paper.

II. TESTS TO DETERMINE FIRE EFFECTS ON INDIVIDUAL UNITS

The main object of the first series of tests was to develop information, on the basis of which the program of fire tests of large walls could be outlined. These initial tests included tile of typical designs and clays on which the effects of fire exposure were determined. The compressive strength, modulus of elasticity, coefficient of expansion, absorption, and body structure of the hollow-tile material were determined, as also the chemical composition of the clays from which the

[3] Circular No. 296, of the Bureau of Standards.

tiles were made, these determinations being made in an effort to discover whatever relations the physical properties and chemical composition of the material have to the effects of the fire exposure.

Clay or shale as obtained from the pit or mine, generally with only a small amount of admixture or inclusion of other materials, is used in the manufacture of hollow tile. The tile are usually burned in round, down-draft kilns in which there may be a considerable variation in temperature from top to bottom of the kiln, this giving a corresponding variation in the hardness of burning of the tile. Also, clays from different sources may produce tile of different characteristics, although the mode of occurrence of the clays may be the same. Hence, the results of a series of tests of hollow tile can have general application only when the number of tests and the field covered are representative of the range of the manufactured product.

1. MATERIAL

Material from 15 different plants was obtained for these tests. Five of them (sources *a*, *b*, *c*, *d*, and *e*) use shale [4] three (sources *k*, *o*, and *q*) surface clay, six (sources *f*, *h*, *l*, *n*, *m*, and *p*) fire clays, and one (source *g*) an equal mixture of shale and fire clay. A given letter designates material from the same source throughout this paper.

(a) CLAYS AND MANUFACTURING DETAILS

Information on the mode of occurrence of the clays and methods of burning is contained in the following extracts of letters from the superintendents of some of the plants from which tile for the tests were obtained:

Source a.—Our raw material is a strong shale which we dig with steam shovel from open pits. In places we find 2 or 3 feet of yellow clay overburden and from 4 to 6 feet of joint clay, but when this is mixed with the pure shale, which lies below, we get a mixture which works well; that is to say, the shale will carry the overburden through in good shape where the overburden is not more than 4 or 5 feet deep. Given good coal and favorable conditions, we water smoke [5] and burn off in from 2½ to 3 days. Our material burns off at from about 1,850 to 1,900° F. but from the appearance of the fire and the ware, there is a variation of from 50 to 100° between the top and bottom of the kilns.

Source b.—Our hollow tile is made from a blue Devonian shale which we have in a 40-foot bank. The shale is mined with a shale planer. We burn our ware in round, down-draft kilns and run a temperature around 1,900° F.

Source d.—Our raw material is a shale taken from the open bank by means of a steam shovel. We are at present working over a 40-foot face, the lower 10 feet being a medium hard, blue shale, the next 20 feet an olive-colored shale not as hard as the blue, and balance of the bank is the olive shale more or less weathered. The burning is done in a 26-foot round, down-draft kiln. The water smoking [6] requires 24 hours, and at the end of it we had a temperature of 800°F. in the top of the kiln. In 24 hours more the kiln is advanced to 1,350° F. Kilns are held at this heat for 14 hours, or until they are a good, clear red on the bottom. In

[4] Appendix A, p. 324. [5] Dehydrate. [6] Dehydration.

the following 12 hours the kiln is raised to 1,625° F., at which point settle starts. The kiln is on settle for 44 hours. There is probably as much as 100° F. difference between top and bottom of kiln.

Source e.—The material we use in the manufacture of our hollow building tile is shale. The overburden consists of soil and sand rock which varies from 6 inches to 2 feet in thickness. The layer of shale below this is brownish, we term it yellow shale. This runs practically uniform in thickness, of about 2½ feet. Below this is a layer of dark blue shale. In burning we first water smoke[7] for about 12 to 16 hours, then gradually bring the kilns up to the required temperature, which is about 1,900° F. Then we endeavor to keep them at this temperature until the bottom of the kiln is, as nearly as possible for us to get it, at the same temperature as the top.

Source f.—The material used in our tile is No. 5 fire clay. Fifteen per cent of shale is thoroughly mixed with this clay, so that the fusion point and the time of burning may be reduced. The green tile remains in the dryer between 30 and 48 hours. The material is burned in round, down-draft kilns. Temperatures for finishing the product range from 1,950 to 2,100° F.

Source g.—We use two materials, shale and fire clay. The former is surface material, the latter occurs under one of the coal seams and is mined with the coal. The materials are used separately or mixed, depending upon the results to be obtained. Our equipment and storage facilities permit us to regulate each material in any proportion desired. The tile forwarded to Washington were of mixture 50 per cent shale and 50 per cent fire clay. The burning requires from 72 to 96 hours, depending upon the proportion of shale to fire clay. All shale tile can be burned in three days, but the fire clay requires four days on account of the longer time necessary to accomplish oxidation. The fire-clay tile requires about 2,200° F, to finish and the shale about 1,900° F. We estimate that there is a difference of about 50° between top and bottom of kiln. The temperatures are only estimated, as pyrometers have not yet been installed.

Source h.—Our clay pit is approximately 25 feet deep, and we work the entire bank in making tile. Approximately 80 per cent of this bank is pure fire clay, and the other 20 is red clay containing a large percentage of iron. This iron will not melt in burning until it has passed 2,200° F. After the tile is placed in the kiln it is fired slowly from 3 to 6 days before we put oil in to raise the fire, and it requires 45 to 55 hours to burn the kiln off with oil. We are not in position to give you the differences in the temperatures between the top and bottom of the kiln. We use Orton pyrometric cones, and we generally bring down a No. 4 cone within 1 foot from the bottom of the kiln and a No. 5 cone 4 feet from the bottom.

Source k.—Clay is procured in open pits in a soft condition and is of sedimentary formation, in the raw state containing, no doubt, 20 per cent moisture. It is burned in round, down-draft kilns, also what is known as the Haig continuous kiln, the results in the end being the same. They are brought up to a temperature of about 2,000° F., the difference between top and bottom being about 75° F.

Source l.—The material from which the samples sent you were made is what is known as No. 6 vein of fire clay, which is found under the No. 6 vein of coal. It is secured by underground mining only. The water-smoking period requires about 24 hours. However, the fires are brought up to full height and closed up tight within the 24-hour period. With a good grade of coal the kilns can be burned off in 48 to 60 hours, depending upon the size of the material in the kiln. This degree of heat will reach from 1,600 to 1,800 °F.

Source m.—The clay is a hard-burning fire clay and is mined. It is found in a 12-foot vein. The ware is set in round, down-draft kilns and brought up gradually to a temperature of about 2,100° F. There is a difference of about 50 to 75° between the top and the bottom.

[7] Dehydrate.

Source n.—Our clays in the mines are located under a soil overburden of from 6 to 15 feet and lie in strata of different thicknesses. Some of it is tough fat clay, and some of it is sandy. The tile are placed in kilns and under slow fire for 12 hours. It then requires from 24 to 48 hours, according to the size of the kiln, to complete the burning. When kilns are finished there is not much difference in the temperature between the top and bottom of the kilns. We, however, frequently do not try to burn the bottom of the kiln as hard as the top, as the bottom of the kiln often contains bricks with sawdust in them to make them porous for nailing purposes.

Source o.—The raw material used in the manufacture of our product is what is ordinarily known as surface clay. It is found in a moist condition except where exposed to the weather, when it dries out. It is practically free from sand and gravel except in a few isolated pockets. The burning process is one which requires 60 hours in a round, down-draft kiln from the time the fires are lighted until they are put out. The temperature at which the material matures is 1,750° F., and there is a probable variation in temperature between top and bottom of kiln of 150° F.

Source p.—The clay is sedimentary, mined in an open pit with a steam shovel, and lies under an overburden of from 3 to 15 feet of red surface clay (glacial deposit). The clay varies in quality in different parts of the pit. Some portions show greater plasticity and are handled much easier from die to drier car because of greater strength of bond while wet. Some portions of the pit yield a clay without much bond when in wet condition and have considerable mica sand content. The material submitted was rather low in bonding strength in the wet condition.

In burning, rise of temperature is not delayed after water smoking but is allowed to proceed as rapidly as the kiln will heat up. Oxidation gives no trouble at all. The average maturing temperature is 2,275° F., in the top and about 2,150° F. in the bottom.

Source q.—We have an ordinary New England clay covered with a layer of so-called peat. The clay is found in a rather granular state for the first 10 or 12 feet, underlaid with a blue clay of great shrinkage. The blue clay will rub to an almost impalpable powder when dry. The tile is burned in down-draft kilns, using coal as fuel. The maturing temperature at the crown is 1,800° F., and in bottom of kiln 1,610° F.

(1) Chemical Analyses.—The chemical analyses of the clays included in the first as well as subsequent series of tests are given in Table 1. Only those represented in the first series will be discussed at this point. The significant items from the standpoint of fire resistance of the burned product are the lime (CaO), the magnesia (MgO), and the total flux content (Fe_2O_3, Mn_3O_4, P_2O_5, CaO, MgO, Na_2O, K_2O). Clays *a*, *b*, *d*, *e*, and *g* show compositions typical for shale. Clay *c*, however, has high lime and magnesia content. The fire clays have low lime and magnesia contents, and the total flux content is smaller than for shales and surface clays. The latter have total flux content of 11.53 to 25.54 per cent and one (*o*) has lime-magnesia content of 15.4 per cent, while the other surface clays (*k* and *q*) have only 1.64 and 4.20 per cent, respectively.

(2) Softening Point.—The softening points of the clays are given in Table 2. These were determined by forming the finely ground clay into cones, comparable in size and form to Orton standard pyrometric cones, and firing them in a gas-fired furnace that was heated to about 1,000° C. in one hour and thereafter regulated to

give a temperature rise of either 50 or 150° C. per hour. The softening point was considered reached when the cone had bent so that the tip was level with the base of the cone. A platinum, platinum-rhodium thermocouple was placed with its junction not more than three-eighth inch from the tip of the test cone or the temperatures were obtained from Orton pyrometric cones mounted on the same plaque as the test cones (see standard C–24–20 of the American Society for Testing Materials).

It is seen from Tables 1 and 2 that low flux content corresponds with high softening point, and that there is a difference of over 200° C. in the softening points of clays with high and with low lime-magnesia content. However, it is seen that the softening points of clays with low lime-magnesia content, while relatively high, may differ among themselves by as much as 175° C., indicating softening effects from the other flux compounds.

TABLE 1.—*Chemical analysis of clays*

Source	Kind of clay	Nonvolatile constituents										Total loss on ignition [2]	Total flux [3]
		SiO_2	Total iron as Fe_2O_3	Al_2O_3 [1]	Mn_3O_4	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3		
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
a	Shale	56.6	11.3	20.5	0.17	2.0	2.5	2.3	0.46	3.4	0.20	10.0	19.07
a–1 [4]		(No representative sample obtained)											
b	Shale	56.0	4.9	20.6	Tr.	.10	7.2	4.7	.1	4.7	1.1	12.7	21.70
c [5]	do	60.3	6.5	20.4	.06	Tr.	3.4	2.8	.92	4.8	.87	1.8	18.48
c–1 [5]	do	60.4	6.0	18.5	.03	.44	4.9	3.6	.95	4.5	.52	1.3	20.42
d	do	61.4	8.6	19.2	.06	1.6	1.1	2.4	.88	4.3	.69	6.2	18.94
d–1 [5]	do	65.2	7.2	18.7	.03	.11	.20	2.2	1.9	4.4	.27	1.2	16.04
d–2 [5]	do	67.8	5.8	19.2	.04	.06	.80	1.8	2.4	2.4	.14	.40	13.30
d–3 [5]	do	64.8	7.5	21.3	.03	.08	.80	1.7	1.6	2.8	.27	.46	14.51
e	do	63.5	6.8	18.7	Tr.	1.6	.53	4.0	1.1	3.0	.26	12.3	17.03
f	85 per cent fire clay, 15 per cent shale.	63.8	1.9	30.4	Tr.	.14	.34	.89	.36	1.8	1.2	9.6	5.43
g	50 per cent shale, 50 per cent fire clay.	66.4	5.8	21.3	Tr.	1.4	.19	1.4	.50	3.2	.26	6.4	12.49
h	Fire clay	69.6	.22	29.1	.08	Tr.	.22	.40	.14	.33	.37	9.1	1.39
j	Surface clay	60.8	6.1	16.9	.04	.31	6.8	2.9	1.4	3.0	1.2	5.2	20.55
k	do	64.6	8.2	21.8	Tr.	.16	.34	1.3	.68	1.8	4.1	11.2	12.48
k–1 [5]	do	66.7	6.0	16.7	.03	.21	3.0	2.7	2.4	2.7	.17	.98	17.04
k–2 [5]	do	70.4	6.6	17.0	.05	.12	1.0	1.1	2.6	1.3	.12	.40	12.77
k–3 [5 6]	do	67.4	5.7	14.9	.02	.18	5.9	2.1	1.6	2.4	.66	1.1	17.90
l	Fire clay	61.8	4.7	27.9	Tr.	.37	.44	.84	.60	2.3	3.8	10.5	9.25
l–1 [5]	do	64.4	2.3	28.2	Tr.	Tr.	Tr.	.96	1.4	3.0	.19	.32	7.66
l–2 [5]	do	71.5	3.3	22.4	.01	Tr.	.78	.51	1.3	.56	.19	.26	6.46
m	do	66.8	1.6	28.9	Tr.	Tr.	.60	.40	.65	.98	1.2	8.0	4.23
n	do	72.5	3.8	19.8	Tr.	.40	.21	.56	.54	1.9	1.2	6.6	7.41
o	Surface clay	57.8	.81	20.4	.06	.40	9.8	5.6	.76	3.9	.45	13.9	21.33
o–1 [5]	do	60.9	5.1	12.8	.04	Tr.	8.8	5.6	2.1	3.9	.85	1.3	25.54
p	Fire clay	67.8	2.4	25.2	Tr.	Tr.	.39	.33	.38	2.4	2.5	9.4	5.90
p–1 [5]	Surface clay	64.6	6.8	24.1	.03	.12	.14	.94	1.7	1.8	.14	.70	11.53
q	do	60.2	5.3	22.8	.09	.50	1.5	2.7	2.2	4.0	.16	4.0	16.29
r [5 7]	do	75.6	1.9	9.4	Tr.	Tr.	[8]	.37	.97	2.2	.08	.44	5.44
r–1 [5 9]	do	63.4	6.2	25.8	.03	.16	.20	.93	1.8	1.8	.10	.50	11.12

[1] Al_2O_3 figure includes any TiO_2 that may be present.
[2] This figure represents total loss on ignition at the temperature of the blast and is the algebraic sum of the various changes, including loss of CO_2. (See W. F. Hillebrand, U. S. Geol. Surv. Bull. 700, 231, and J. W. Mellor, Treatise on Quantitative Inorganic Analysis, pp. 157–159). The results for samples *k*, *l*, *m*, *n*, and *p* are apparently too high, probably owing to the reduction of sulphate to sulphide by the organic matter present.
[3] Total flux includes Fe_2O_3, Mn_3O_4, P_2O_5, Cao, Mgo, Na_2O, and K_2O.
[4] A mixture of 60 per cent shale, 10 per cent soapstone, and 30 per cent fire clay.
[5] Analysis made on the burned clay. All others on the raw clay. Organic matter detected in all samples of raw clay. Appreciable amount being present in samples *f*, *g*, *h*, *j*, *k*, *l*, *m*, *n*, and *p*.
[6] Actually a weathered shale.
[7] Actually a mixture of pottery clay, fire clay, and fire sand. Analysis applies for tile in tests 40 and 41.
[8] Not detected.
[9] From same source as *r* but apparently different mixture. Analysis applies for tile in tests 65 and 66.

TABLE 2.—*Softening points of hollow-tile clays*

Source	Kind of clay [1]	Softening point		
		Cone No.	°C.	°F.
a	Shale		1,100	2,012
b	do		1,140	2,084
c	do		1,145	2,093
c-1	do	1	1,160	2,120
d	do		1,180	2,156
d-1	do	3	1,170	2,138
d-2	do	7	1,250	2,282
d-3	do	9	1,285	2,345
e	do		1,240	2,264
f	15 per cent shale, 85 per cent fire clay		1,390	2,534
g	50 per cent shale, 50 per cent fire clay		1,325	2,417
h	Fire clay	19	1,515	2,759
j	Surface clay		1,170	2,138
k	do		1,335	2,435
k-1	do	2	1,165	2,129
k-2	do	8	1,260	2,300
k-3	do	3	1,170	2,138
l	Fire clay		1,350	2,462
l-1	do	18	1,490	2,714
l-2	do	19	1,520	2,768
m	do	20	1,525	2,777
n	do		1,390	2,534
o	Surface clay		1,130	2,066
o-1	do	2	1,165	2,129
p	Fire clay	19	1,515	2,759
p-1	Surface clay	17	1,475	2,687
q	do		1,330	2,426
r	do	16	1,465	2,669

[1] The clays designated here as fire clays are not strictly comparable with the true fire clays from which refractories are made. They contain various amounts of impurities, some of which act as fluxes and give the burned-clay body the strength necessary for structural purposes.

(b) TILE

The sizes and designs of tile included in these tests are given in Table 3. The letter designations for the designs refer to sketches in Figure 13 (p. 50), which illustrate all of the tile designs included, with the exception of the 4-cell, 8 by 12 by 12 inch partition tile, which had one transverse web in each direction that divided the interior space into four approximately equal cells.

(1) COMPRESSIVE STRENGTH AND ABSORPTION.—When the work reported in this paper was begun the method of making the compression and absorption tests of hollow tile had not been standardized. A number of preliminary tests were made in which various methods were tried, the results of which have been published.[8] This work showed that the most practicable capping material for application to the bearing ends or faces of tile units to be subjected to compression tests consists of a mixture of three volume parts of Portland cement and one of calcined gypsum (plaster of Paris) mixed with water to suitable consistency. Such a cap, aged from three to seven days, was used in all compression tests reported in this paper.

[8] "Capping for compression specimens," J. Am. Cer. Soc., **6**, No. 5, pp. 623-629; May, 1923.

The preliminary absorption tests showed that boiling the specimens in water at atmospheric pressure from one to five hours, while not giving as close an approach to complete saturation as boiling at lower pressures, gave results one-fifth to one-fourth higher than by immersion in water at room temperature for three days.[9] As the difference between results with the one-hour and five-hour boilings was less than 1 per cent absorption for any tile, provided the specimens were left in the water until it cooled to room temperature, the one-hour boiling method was used for most of the tests reported in this paper. In the earlier tests the saturation was made by boiling for five hours.

The results of the compressive strength and absorption tests of the tile used in this series of fire tests are given in Table 3a. The modulus of elasticity of the tiles that were tested on end, obtained in making the compression tests, is also recorded in this table.

The manufacturers were instructed to send tile representative of their full range in burning, and the tile received were apparently representative of this range in most cases. This is indicated by strength and absorption variations of 50 per cent or more for the tile from some of the sources. These variations may be greater than would be the case for commercial shipments.

(2) STRUCTURE.—The tile made from the shales and the dense-burning fire clays were nearly free from laminations, while some of those from the open-burning fire clays and surface clays (*k*, *n*, and *p*) showed a decidedly laminated structure. Laminations in tile from the other surface clays were of intermediate degree.

(3) EXPANSION.—The expansion of the tile material with temperature was determined by the interferometer method.[10] The test specimens for each determination were prepared from three pieces taken from different parts of the same tile, or from three different tiles from the same source. The expansion curves obtained from these tests are given in Figures 1, 2, and 3, and the average coefficients of expansion are given for four temperature ranges in Table 3b. In making these tests it was observed that when a second run was made on a subsequent day a slightly higher expansion coefficient was obtained. At the time the first run was made the specimens, although conditioned at 100° C., contained moisture that had caused an initial expansion. This was driven off during the first run, so that when the second run was started the specimen was in the condition that the material was in when it came from the kiln. However, tile in building walls would contain some moisture; hence the values obtained from the first run were chosen for use in discussing the results of these tests.

[9] "Effectiveness of different methods of making absorption determinations as applied to hollow building tile," J. Am. Cer. Soc., 5, No. 11, pp. 788–797; November, 1922.

[10] For description of method, see B. S. Sci. Paper No. 485, Application of the Interferometer to Measurements of the Thermal Dilatation of Ceramic Materials.

TABLE 3a.—*Compressive strength and absorption of hollow tile used in preliminary fire tests*

Source	Clay	Design of unit [1]	Nominal size (inches)	Number of tests	Average weight	Absorption		Position in test	Average area under load		Compressive strength				Average modulus of elasticity (net area) in million pounds per square inch
											Gross area		Net area		
						Range	Average		Gross	Net	Range	Average	Range	Average	
					Pounds	*Per cent*	*Per cent*		*Sq. in.*	*Sq. in.*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	
a	Shale	(2)	8 by 12 by 12	4	27.8	6.6–12.4	8.4	End	96.1	30.0	1,180–1,800	1,510	3,590–5,770	4,840	4.350
a	do	(2)	do	3	27.8	6.0–12.3	8.8	Side	96.5	17.9	390– 560	490	2,080–3,030	2,640	
b	do	K	8 by 5 by 12	3	15.4	1.7–16.5	7.8	End	39.4	17.8	860–2,360	1,500	2,050–5,060	3,280	4.990
b	do	K	do	2	15.4	1.4–17.9	9.6	Side	93.4	20.4	720– 750	740	3,270–3,490	3,380	
b	do	L	do	3	14.3	13.9–16.4	15.5	End	40.0	17.7	2,270–2,800	2,540	5,120–6,230	5,730	3.430
b	do	L	do	1	14.3		18.1	Side	96.2	22.6		690		2,920	
c	do	B	8 by 12 by 12	3	28.5	7.7–11.0	9.7	End	93.4	29.6	1,280–1,480	1,360	4,040–4,570	4,290	6.060
c	do	B	do	3		8.1–12.5	9.7	Side	95.6	19.0	330– 400	360	1,610–2,030	1,820	
d	do	A	do	5	35.5	6.4–10.9	8.5	End	92.0	38.2	1,970–3,450	2,830	4,700–8,230	6,820	4.830
d	do	A	do	5		7.1–10.6	8.6	Side	93.3	21.8	1,260–1,930	1,560	5,430–8,220	6,670	
d	do	L	8 by 5 by 12	4	14.6	8.6–10.9	9.9	do	94.0	22.2	1,290–1,620	1,380	5,350–6,680	5,730	
e	do	L	do	3	14.4	12.9–14.2	13.4	End	40.6	17.4	1,440–1,680	1,530	3,380–3,850	3,580	2.650
e	do	L	do	5	15.3	11.1–14.8	13.2	Side	98.2	23.0	570– 880	690	2,390–4,050	2,970	
f	85 per cent fire clay, 15 per cent shale.	(3)	8 by 12 by 12	5	28.4	10.9–13.7	12.4	End	100.6	34.4	1,080–1,970	1,520	3,000–5,920	4,450	2.730
f	do	(3)	do	3		12.1–13.5	12.6	Side	99.9	21.4	290– 360	310	1,280–1,700	1,470	
g	50 per cent fire clay, 50 per cent shale.	(3)	do	5	32.7	6.9–11.1	8.9	End	98.4	36.6	1,200–2,200	1,610	3,180–6,070	4,330	4.810
g	do	(3)	do	4		8.6– 9.8	9.4	Side	94.0	20.5	870–1,160	980	3,900–5,430	4,480	
h	Fire clay	A	do	5	33.8	14.5–17.2	15.6	End	90.4	41.8	1,090–1,570	1,410	2,350–3,330	3,040	1.820
h	do	A	do	3		15.2–17.0	16.4	Side	93.0	26.3	310– 370	340	1,090–1,310	1,190	
k	Surface clay	B	do	4	33.6	7.8–19.2	13.9	End	91.8	43.6	1,370–2,040	1,690	3,030–4,340	3,550	4.150
k	do	B	do	3		11.4–17.4	13.5	Side	91.6	27.2	280– 440	360	970–1,440	1,190	
l	Fire clay	A	do	5	34.7	10.8–15.0	11.9	End	98.3	41.0	1,590–3,010	2,550	3,830–7,130	6,100	
l	do	A	do	5	35.5	10.6–12.5	11.9	Side	96.4	22.0	850–1,090	990	3,780–4,810	4,320	
l	do	L	8 by 5 by 12	6	14.9	5.9–10.4	7.9	End	41.8	17.5	1,330–2,420	2,020	3,240–5,780	4,840	4.540
l	do	L	do	2	14.8	6.4– 8.6	7.5	Side	97.1	22.4	1,030–1,700	1,360	4,610–7,160	5,890	
m	do	L	do	3	16.2	6.7–10.6	8.7	End	40.1	17.9	1,500–2,830	2,300	3,370–6,280	5,170	
m	do	L	do	3	16.1	6.8–10.3	8.8	Side	98.3	21.5	610– 950	770	2,730–4,250	3,440	
m	do	E	8 by 12 by 5	6											

m	----do----	L		3	16.2	6.7–10.6	8.7	End	40.1	17.9	1,560–2,830	2,300	3,370–6,280	5,170	3,330	
m	----do----	L	----do----	3	16.1	6.8–10.3	8.8	Side	98.3	21.5	610– 990	730	2,830–4,270	3,340	----	
m	----do----	E	8 by 12 by 5	6	17.2	----	----	End	93.8	37.5	1,680–3,400	2,820	4,190–8,780	7,090	----	
n	----do----	A	8 by 12 by 12	5	30.8	8.7–14.5	12.3	----do----	91.8	38.3	1,780–2,720	2,250	4,440–6,560	5,400	3,050	
n	----do----	A[a]	----do----	5	31.0	8.7–13.0	11.1	Side	91.4	19.6	460– 680	580	2,080–3,300	2,720	----	
o	Surface clay	(?)	----do----	5	28.9	22.7–25.8	24.8	End	94.8	39.8	680–1,290	980	1,600–3,080	2,300	----	
o	----do----	(?)	----do----	5	28.9	22.7–25.6	24.1	Side	96.3	26.2	310– 690	420	1,160–2,460	1,550	1,020	
p	Fire clay	B	----do----	5	35.0	11.0–15.7	12.9	End	92.8	42.0	1,230–2,020	1,680	2,710–4,460	3,700	----	
p	----do----	B	----do----	5	35.9	12.2–15.6	13.6	Side	94.2	21.8	470– 610	540	1,980–2,620	2,360	----	
q	Surface clay	A	----do----	5	32.4	2.4–15.3	9.8	End	91.7	37.4	1,860–3,870	2,640	4,490–11,060	6,640	----	
q	----do----	A	----do----	4	33.7	16.0–17.7	16.9	Side	99.9	21.6	410– 540	490	1,810–2,690	2,300	----	
s	50 per cent shale, 50 per cent surface clay.	L	8 by 5 by 12	5	13.4	10.2–12.0	10.8	----do----	94.1	20.3	1,150–1,450	1,270	5,370–6,700	5,880	4,420	

[a] See Figure 13.

[b] 4-cell partition tile. Not shown in sketch.

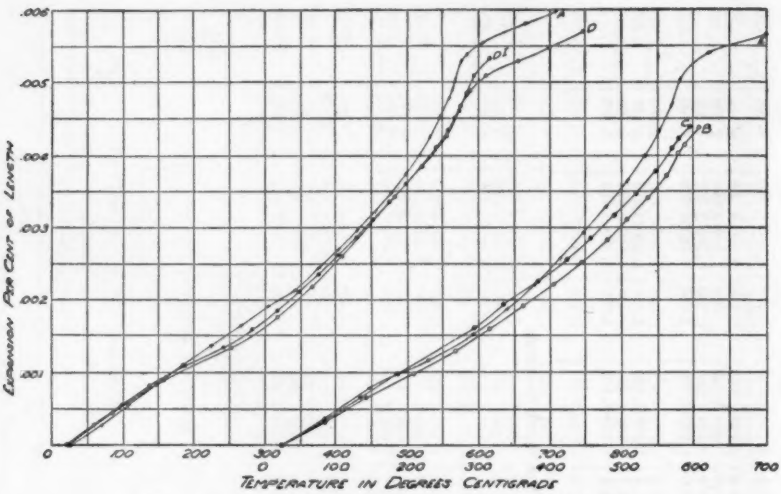


FIG. 1.—*Expansion curves of samples of shale tile*
(For letter designation see text page 18)

TABLE 3b.—*Summary of physical and chemical properties of hollow-tile material*

Source	Coefficient of expansion, millionths per ° C.				Compressive strength (net area on end)	Modulus of elasticity	Total flux	Lime magnesia
	Room to 300° C.	300 to 500° C.	300 to 600° C.	500 to 600° C.				
					Lbs./in.²	*Million lbs./in.²*	*Per cent*	*Per cent*
a	6.93	9.40	12.7	17.5	4,840	4.350	19.07	4.80
b	5.94	7.70	9.3	12.4	3,280	4.990	21.70	11.90
c	6.07	8.05	9.2	11.5	4,290	6.060	18.48	6.20
d	5.89	10.05	11.2	13.7	6,820	4.830	18.94	3.50
d-1	6.17	9.60	11.6	15.7			16.04	2.40
e	5.70	9.85	12.4	17.5	3,580	2.650	17.03	4.53
f	3.55	7.60	10.3	15.6	4,450	2.730	5.43	1.23
g					4,330	4.810	12.49	1.59
h	6.25	5.95	6.4	7.2	3,040	1.820	1.39	.62
j	7.11	9.85	12.8	18.8	[1] 2,760	[1] 1.830	20.55	9.79
k	5.36	7.75	9.7	13.6	3,550	3.595	12.48	1.64
l	5.89	7.85	9.3	12.2	4,840	4.540	9.25	1.28
m	6.83	5.75	6.8	8.8	5,170	3.330	4.23	1.00
n	5.38	6.95	8.7	12.1	5,400	3.050	7.41	.77
o	7.32	10.50	12.8	17.3	2,300	1.620	21.33	15.40
p	4.84	6.15	8.3	12.6	3,700	2.920	5.90	.72
q	5.07	7.60	9.0	11.9	6,640	4.420	16.29	4.20

[1] From Table 14, p. 72.

It is seen that the rate of expansion rises with temperature and that the change is particularly marked for the region 500° to 600° C., within which is contained the transformation point of quartz, which is accompanied by a relatively large expansion.

There are also given in Table 3b, for convenience of reference, the average ultimate strength and the modulus of elasticity as determined in the strength tests reported in Table 3a, and also the total

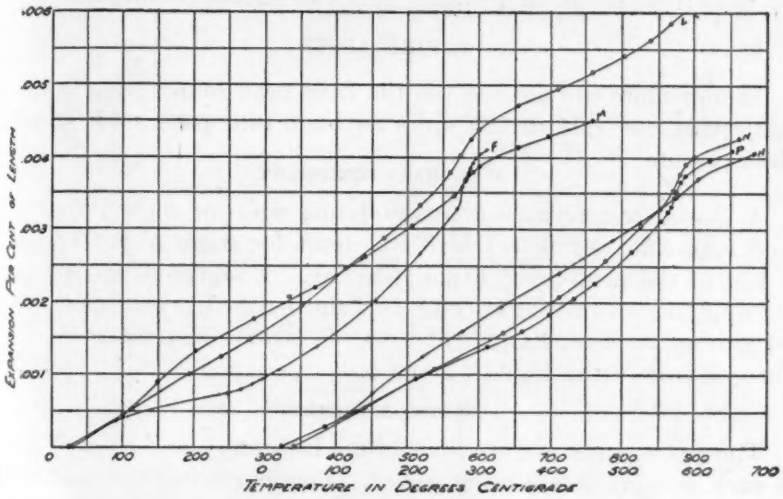


FIG. 2.—*Expansion curves of samples of fire clay tile*
(For letter designation see text page 18)

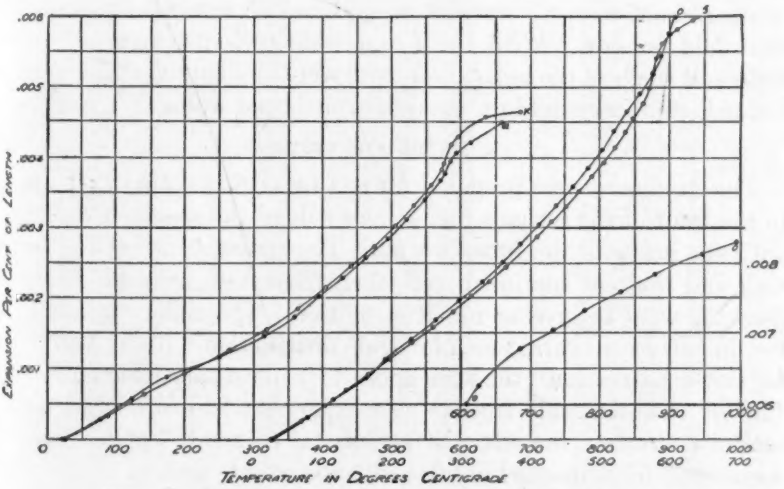


FIG. 3.—*Expansion curves of samples of surface clay tile*
(For letter designation see text page 18)

flux and lime-magnesia content from the chemical analyses given in Table 1.

(4) WEATHERING RESISTANCE.—At the time of making the compression, absorption, and expansion tests, samples from the same

units were subjected to freezing and thawing tests. The results from these tests have been published [11] and were used by committees of the American Society for Testing Materials and the Federal Specifications Board in drafting specifications for hollow tile.

2. FIRE TESTS

Two or more fire tests of the tile from each source were made by subjecting one side of the units as built into piers to a standard fire exposure.

(a) FURNACE EQUIPMENT

A special test furnace accommodating walls or piers 1 foot wide and approximately 6 feet high was built for these tests, the center 4 feet of the piers being exposed to fire. Equipment was provided for applying a constant working load during the fire exposure and for measuring the temperatures of both the furnace and the walls. The furnace is shown in Figures 4 and 5.

(b) TEST SPECIMENS

The test specimens were built in the laboratory and allowed to age a week or more before being tested. The mortar used consisted of 1 part (by loose volume) of Portland cement, 1 part of hydrated lime and 4 parts of building sand. For the tests reported in this series, all end-construction tile [12] were set on end and all side-construction tile [12] were laid on side. With the 1-foot wide test specimen, all vertical webs and shells of the individual units were in alignment and were well bedded, conditions seldom obtaining for larger walls.

(c) METHOD OF TESTING

The specimens were prepared for test by setting them in the opening in the front of the furnace (fig. 4), one side of the specimen being even with the inside of the furnace wall. The spaces between the furnace wall and the test specimen were then filled with asbestos board and asbestos wool to give as much insulation as possible. Loads of 120 lbs./in.^{2} of gross-bearing area for end-construction [12] tile and 60 pounds for side-construction [12] tile were applied by means of a lever and weights (fig 5). Considerable trouble was experienced in obtaining uniform load distribution, the effect of accidental eccentric application being apparently more marked in tests with tile on side than in those with tile on end. For this reason some tests made with end-construction tile on side are not here reported, as the tile would not normally be used in this position; also some of them were 4-cell partition tile.

The time-temperature reference curve by which the fire exposure was controlled is that standard for American fire testing practice and is given in Figure 18 (p. 88). The fire exposure was usually continued

[11] "Strength, absorption, and freezing resistance of hollow building tile," J. Am. Cer. Soc., 7, No. 3 pp. 189-199, March, 1924.

[12] Appendix A, p. 324.

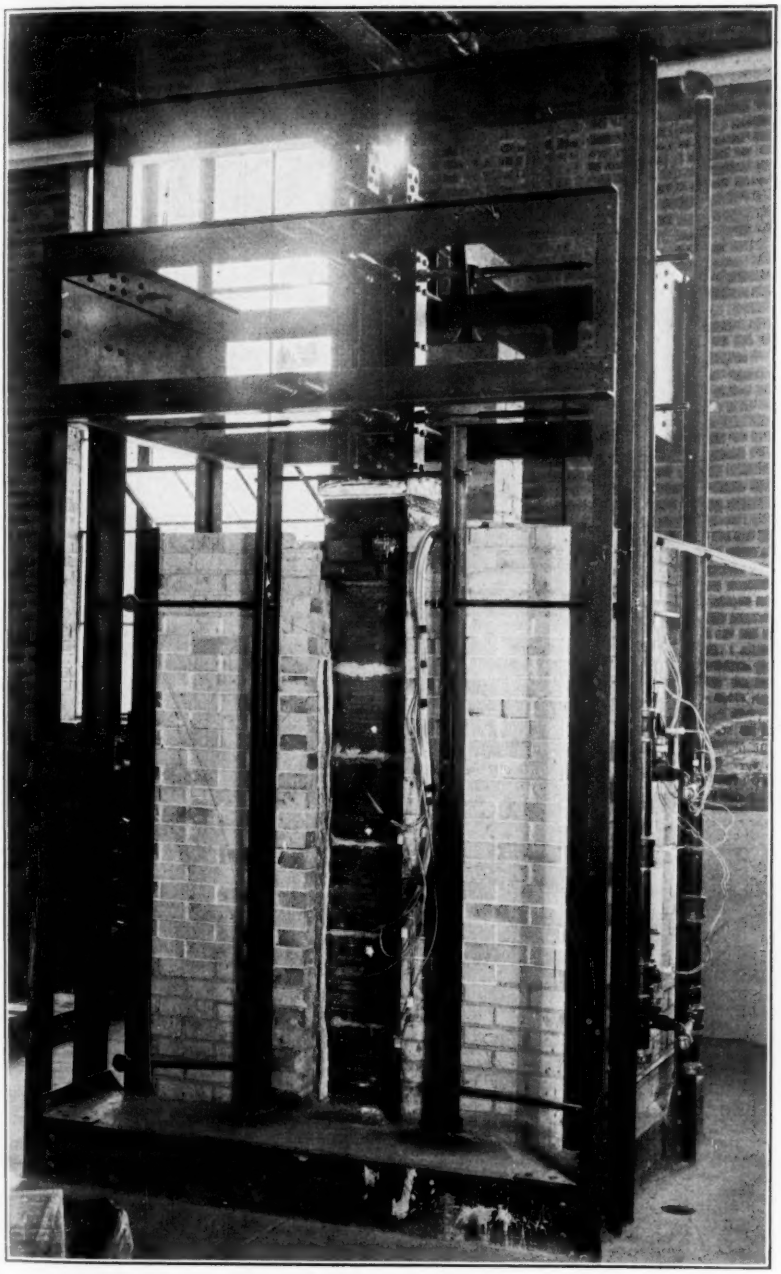


FIG. 4.—*Original testing furnace showing specimen in position and loaded preparatory to fire test*

UNIV. OF MICH.

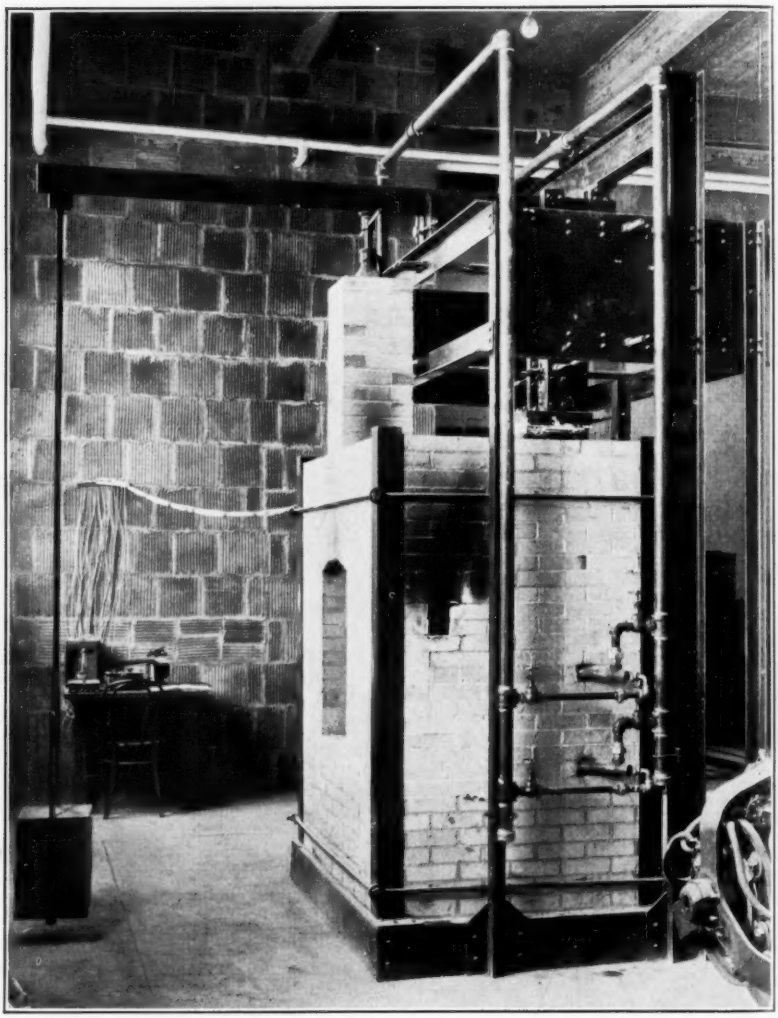


FIG. 5.—*Side and rear of original testing furnace showing temperature measuring apparatus and method of loading test specimen*

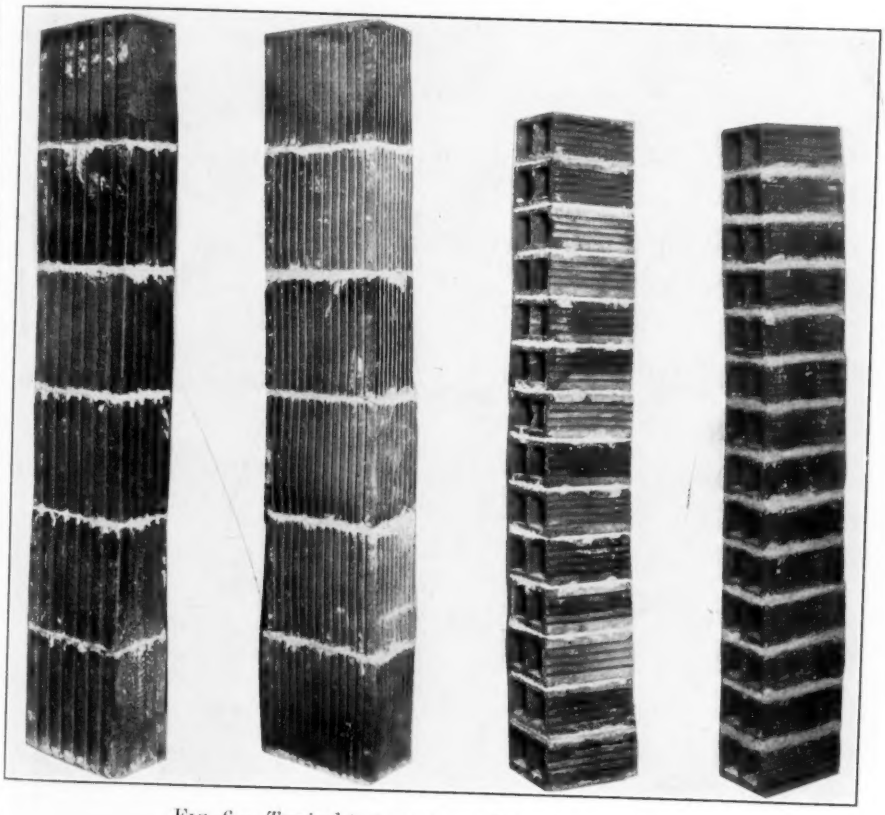


FIG. 6.—*Typical test specimens before fire exposure*

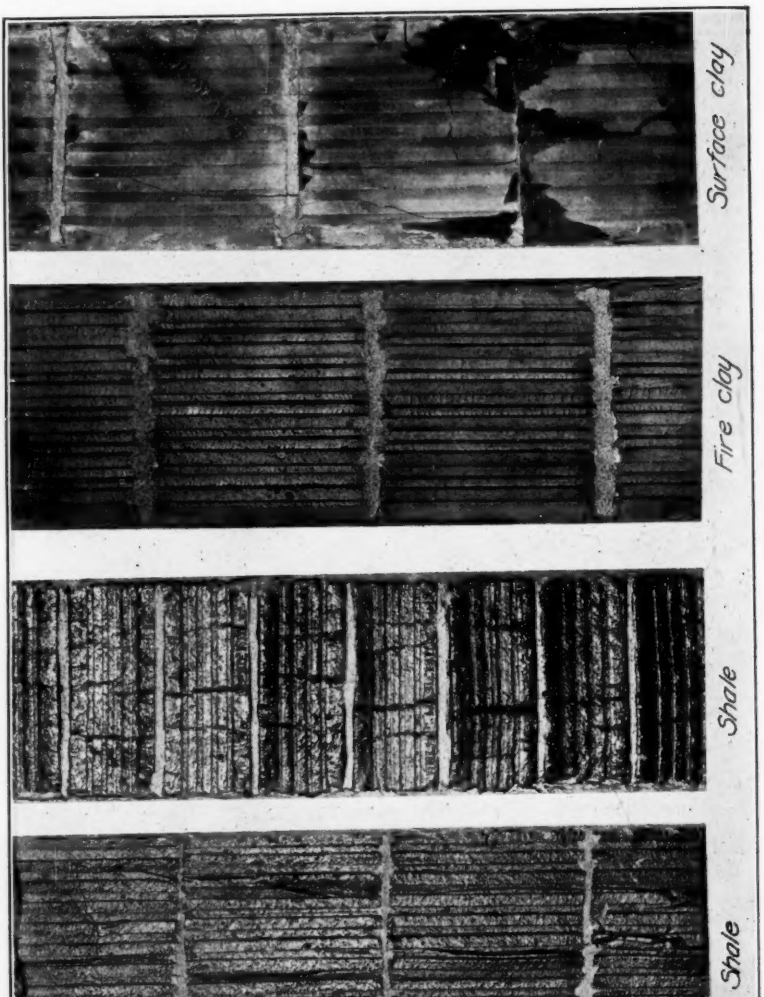


FIG. 7.—*Exposed side of typical test specimens after fire exposure*

for six hours unless failure of the specimen under load occurred sooner. Some tests were stopped at one and one-half hours, to ascertain the effects of moderate fire exposure.

Measurements of the temperatures of the furnace, of the cells of the units, and of the unexposed surface were made. The furnace temperatures were generally near the temperatures indicated by the reference curve. No temperature data from this series of tests will be included, since the 1 by 6 foot specimen was not large enough to assure representative conditions, although the data obtained were informative. Temperature data from fire tests of larger specimens are given in Section IV of this paper.

3. RESULTS

Views of typical specimens after test are given in Figures 6 and 7. The results as they concern fire effects on the tile can be summarized by grouping together tests with tile from similar clays.

(a) SHALES

Tests were made of tile from three hard-burning shales (*a*, *c*, *d*), the burned product having absorptions from 8.5 to 9.7 per cent as based on averages from each source (Table 3a). For two shales tested, *b* and *e*, the tile were less hard, the average absorptions being near 13 per cent. The structure of all shale tiles was uniform without apparent laminations.

The end-construction tile *a* were 8 by 12 by 12 inch 4-cell tile, and *c* were 6-cell tile of the same size. The side-construction tile *b*, *d*, and *e* were 8 by 5 by 12 inch 2 or 3 cell back-up tile (fig. 13, p. 50, designs K and L). One test from source *d* was also made with end-construction 6-cell tile. The percentage of cell space based on the whole volume of the unit ranged from 55 to 68. The specimens supported working loads under fire exposure for periods from 2 hours 9 minutes to over 6 hours, the low period being with tile from source *c*. This should not be taken as saying that a wall of similar tile would necessarily support load under similar fire conditions for such periods, since the larger construction may deflect more, is weaker due to methods of bonding used, and is generally subject to more destructive effects from heat than the small pier construction tested. This applies in all cases where fire endurance in this series of fire tests is mentioned. The tests as made give a good criterion of the amount of fire damage sustained by the units.

Almost all shells on the fire side of the shale piers were loose or could be easily broken off after test. A considerable amount of damage extended beyond the center longitudinal web and to the unexposed shell of the tile. Most of the effects near the fire side took place early in the test during the period of rapid furnace-temperature rise. Some glazing, shrinkage, and fusion occurred at between four and six hours in the longer tests.

(b) FIRE CLAYS

Tile from six sources using fire clay were tested. Due to the great difference in the physical properties of tile from these clays, they are divided into two groups, the first group consisting of dense-burning material and the second group of open-burning material.

(1) DENSE-BURNING FIRE CLAYS.—This group included material from three fire clays (*f*, *l*, and *m*), which are comparatively pure, dense-burning, and yield a uniform buff-colored tile, the clay *f* being a mixture of 15 per cent shale and 85 per cent fire clay. The average percentage absorption ranged from 7.8 to 12.5 for the different groups, with variations within each group of not more than 25 per cent from the average for the group. The texture of all tile was uniform without apparent laminations. The end-construction tile, *f*, was 8 by 12 by 12 inches with four cells. Some tile from source *m* were 8 by 12 by 5 inch end-construction double-shell tile, same as Figure 13 D except that there were five interior webs between the two shells. The side-construction tile *l* and *m* were 8 by 5 by 12 inch 2-cell back-up tile. The percentage of air space ranged from 55 to 58.

Four tests on end-construction tile were made, one of which (from source *f*) failed under load after 5 hours 20 minutes fire exposure. This was the only load failure of fire-clay tile and is not significant, since the period developed is much beyond the normal resistance period of 8-inch walls. Three tests of side-construction tile were made to six hours, and one each of side and end construction were stopped at one and one-half hours. During the tests there was generally little indication of any decided effects. After the tests, however, from one-third to all shells on the fire side were loose or could be easily loosened. There was no apparent difference in behavior between the regular end and side construction tile.

(2) OPEN-BURNING FIRE CLAYS.—This group included material made from three fire clays, *h*, *n*, and *p*, somewhat more impure than those described under (1) above, the color of the burned product being light buff or russet. The absorption ranged from 11.1 to 16.4 per cent on average values. All tile in this group were 8 by 12 by 12 inch 6-cell end-construction units having approximately 55 per cent of cell space. Six tests were made with the tile on end, 3 to 1½ hours and 3 to 6 hours.

Tile from sources *n* and *p* came through the tests with about three-fourths of the total number of units undamaged as far as examination could disclose. They had a laminated structure and also ample fillets. Tile from the third source (*h*) was apparently somewhat different in composition, had very small fillets and a less laminated structure. In the tests with the tile on end the exposed shells were all loosened.

(c) SHALE AND FIRE-CLAY MIXTURE

The tile from source *g* was made of a mixture of equal parts of shale and fire clay. They were uniformly burned and had an absorption of approximately 9 per cent. The tile were free from laminations, but the surface was blistered and spalled, probably from lime pebbles. The units were 8 by 12 by 12 inch 4-cell end-construction tile having five-eighths-inch webs and shells, the percentage of cell space being 62.

Two tests were made, 1 to 1½ hours and 1 to 6 hours. Flaking and cracking on the exposed surface of the specimen were noted at 15 to 30 minutes and cracking on the unexposed surface at 2 hours. After test all exposed shells were loose. Little cracking took place back of the center longitudinal web.

(d) SURFACE CLAYS

Tile from three surface clays were tested. Tile from source *o* were soft, light to dark pink in color, depending on the hardness, and had a uniform structure. The absorption varied from 22.7 to 25.8 per cent. The units were 8 by 12 by 12 inch 4-cell end-construction tile, the percentage of cell space being 58.

Two fire tests were made, one of which was stopped at 1½ hours. In the other test, failure under load occurred at 2 hours 19 minutes. Cracks on the exposed surface and surface spalling were noted during the first 30 minutes, and cracks on the unexposed surface within 1 hour. After the tests all of the exposed shells were loose and cracks extended through several units.

Units from source *k* were medium to hard burned, dark red, laminated tile, the average absorption being 13.7 per cent. The tile were 8 by 12 by 12 inch 6-cell end-construction, having double center transverse webs (fig. 13 B). The shells and webs were from ¾ to 1 inch thick, the percentage of cell space being 53. The units had very small fillets.

Two fire tests were made, 1 to 6 hours and 1 to 1½ hours. Cracking on the exposed surface was noted in 20 minutes after the start of the test. No cracks on the unexposed surface were apparent during the test. After the test all exposed shells were loose, most fractures being at junctions of shells and webs. No cracks extended beyond the center longitudinal webs.

Tile from the source *q* were of light to dark red color, the range in hardness being quite large. The structure was fairly uniform with few laminations. The units were 8 by 12 by 12 inch 6-cell end-construction tile having webs and shells about ¾ inch thick and cell space of 60 per cent.

Two tests were made, one being stopped at 1½ hours and one at 6 hours. In one test a crack was noticed on the unexposed surface at 30 minutes and fine cracks were noted on the unexposed surface at

1½ to 3 hours. After the tests almost all of the exposed shells were loose or the webs holding them were cracked. No cracks were noted back of the center longitudinal web.

Generally, for the surface clays considerable glazing, shrinkage, and some fusion took place near the end of the 6-hour tests.

4. SUMMARY AND DISCUSSION

(a) CLAY CHARACTERISTICS

The chemical analyses of the clays from which the tile were made (Table 1), taken together with the results of these tests, indicate that clays having high total flux or high lime-magnesia content were the most damaged by the fire exposure from the standpoint of ability to carry load. A petrographic examination of the clays indicated quartz contents from 5 to 40 per cent, but no consistent relation was found between quartz content and thermal expansion, or the effects of fire exposure.

(b) TILE CHARACTERISTICS

The expansion data (figs. 1, 2, and 3 and Table 3b) show that the expansion of the surface-clay tiles of high lime-magnesia content and some of the shales is relatively high. For the shale tile there is, however, no consistent relation between coefficient of expansion and lime-magnesia content, but tile from shale *c* that was high in lime-magnesia, in common with those from *o*, apparently suffered the most fire damage. The modulus of elasticity and the strength of the material would, to some extent, affect the amount of damage to the units, the most favorable combination being low coefficient of expansion, high strength, and low modulus of elasticity, in which case the unequal expansion due to heating on one side would be taken care of by adjustments within the clay body. High strength, however, usually also means a high modulus of elasticity. The most favorable conditions actually obtainable, therefore, would be intermediate range in strength and modulus of elasticity, combined with low coefficient of expansion. With the surface-clay tile *o*, which had low modulus of elasticity and low strength as well as high coefficient of expansion, the fire damage was very severe. With the open-burning fire clays *h*, *n*, and *p*, which had intermediate or low modulus of elasticity and intermediate or high strength as well as a low coefficient of expansion, the fire damage was smaller than for any other group. Of the dense-burning fire clays, *m* having low expansion, intermediate modulus of elasticity, and high strength, showed less effects from fire than tile from the other two clays (*f* and *l*) contained in this group.

The structure of the material did not appear to be important from the standpoint of fire damage. Some of the most laminated tile were the most fire resistive, the laminations possibly assisting in adjustments within the body from unequal heating. This property,

however, has an important bearing on strength, especially of side-construction tile, and on resistance to freezing.

The thickness of shells and webs had a decided effect on the results, as it concerns ability of the wall to carry load under fire exposure, considerable difference being noted between tile having 55 and 60 to 68 per cent cell area, the results with the heavier tile being uniformly more favorable. No appreciable increase in freedom from fire effects could be noted, however, with the tile having heavier shells than seven-eighths inch.

III. EFFECT OF DESIGN AND MANUFACTURING DETAILS

Although the requirements of hollow-tile production generally demand that the clay be used as mined with only a limited amount of mixing with other materials, there are several details in the design of the units and methods of manufacture that might affect the fire resistance of the tile. These include the addition of grog (ground burned clay or broken tile) or combustible fillers to the clay, finer grinding, or additional pugging of the clay, burning to different degrees of hardness, design of the unit, thickness of shells, and size of fillets.

1. TESTING EQUIPMENT

The equipment used for conducting these tests consisted of frames for containing the test walls, a crane for handling them (fig. 8), the furnace for making the fire exposure, including a restraining frame with hydraulic jack for loading the walls (fig. 9.), and a thermocouple installation for furnace control and for obtaining temperatures in the cells and on the unexposed surface of the test wall.

The rear and two sides of the furnace are of fire-brick construction, the front being closed by the test wall and its frame. The combustion chamber is approximately 2 feet deep, 4 feet wide, and 4 feet high. Vent holes for the escape of the products of combustion are placed in the back and in the crown of the furnace. Gas taken from the city mains was used for fuel. Four air-blast burners, distributed from top to bottom, were located on each side of the furnace. The burners were directed so that the flame impinged at a small angle on the back of the furnace which curved outward toward the center of the test wall. By using only enough air in the gas burners for partial combustion, and by supplying the additional air required through auxiliary air inlets, it was possible to obtain a flame which bathed the entire exposed surface of the test wall. The variation in temperature between different portions of the chamber was generally less than 20° C. except during the first one-half hour of the tests.

Fifteen frames of reinforced concrete for which crushed fire brick was used as aggregate were provided for holding the test walls. Five of these frames were built solid, so that the wall could be tested

under restraint, thus simulating a partition or panel wall in buildings of fire-resistive construction. The remaining 10 frames were built with the top member detachable, to permit loading of the walls. The restraining frame was made of a heavy I beam placed parallel to and 2 feet above the top of the wall frame and connected by means of channels, serving as tension members, to the ends of a 6-inch H beam embedded in the bottom of the wall frame. A similar H beam was embedded in the top member of the frame to distribute the load over the wall length. The load was applied by means of a water-cooled hydraulic jack, placed between the top member of the restraining frame and the top member of the wall frame.

All temperature measurements were made by the thermoelectric method. Six alumel-chromel thermocouples protected with porcelain or iron tubes were used to measure the furnace temperature and three couples, symmetrically arranged about the center of the test wall, indicated the temperature of each set of cells in the wall. The temperature of the unexposed surface of the wall was obtained with three couples of No. 24 iron-constantan wire similarly arranged. In some of the later tests the temperature of the unexposed surface was also obtained with thermometers, the bulbs of which were covered with 6-inch asbestos felt pads, four-tenths inch thick. Wire of similar thermoelectric properties as that in the couples was also used for the leads to the cold-junction box (fig. 9), the cold junctions being iced, thus eliminating cold-junction corrections.

2. CONSTRUCTION OF TEST WALLS

The test walls were built by experienced masons, some of whom were in the employ of the bureau, and others were obtained for short periods from a contractor doing local construction work. Mortar of 1 part by volume of Portland cement, 1 part of hydrated lime, and 4 parts of sand was used for all of the walls of this series. All of the walls were stored in a heated room at least 30 days before being tested. End-construction tile was always set with cells vertical and side-construction tile with cells horizontal.

3. TESTING METHODS

The test consisted generally of subjecting one side of the specimen to fire exposure while a constant working load was applied, the comparative fire resistance afforded by the walls being obtained from the time the walls were able to carry the load or, in case this was greater than six hours, from the condition of the individual units as observed when dismantling the wall. In some cases the walls, loaded or unloaded, were subjected to short fire exposures and the fire effects measured by the loss of compressive strength, as determined from comparative tests of individual units from the fire-tested walls and units not subjected to the fire exposure.

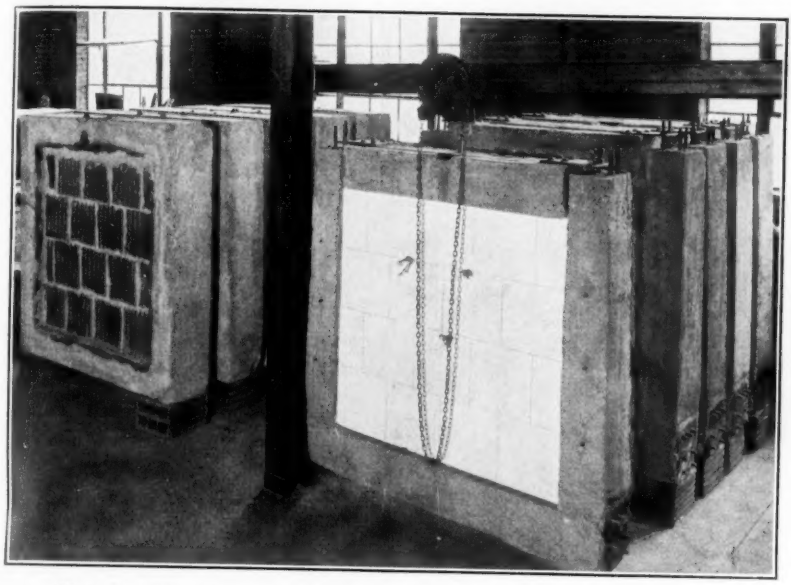


FIG. 8.—*Showing storage of small walls while aging them before test*

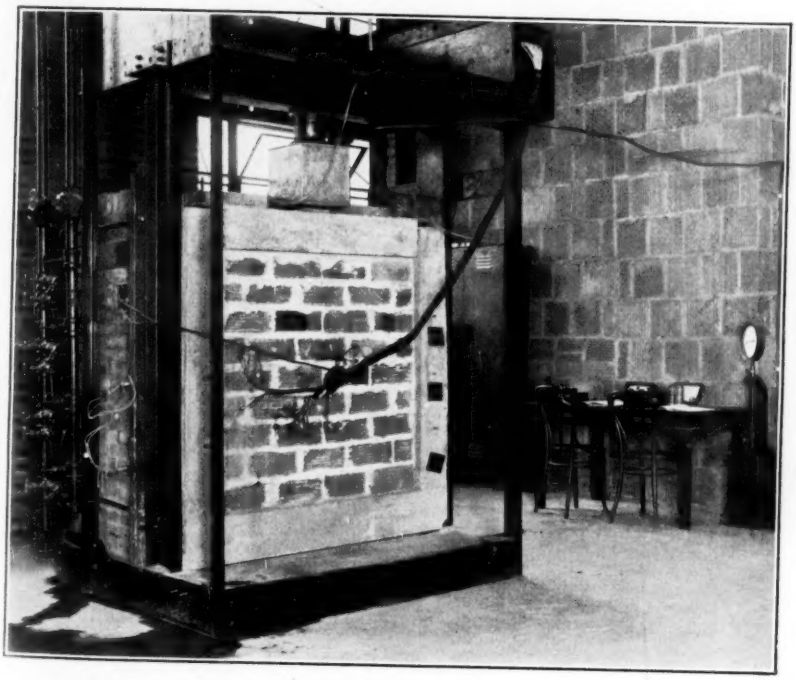


FIG. 9.—*Small test furnace showing wall prepared for test*

The fire was controlled to approximate the standard reference curve recommended in the American Engineering Standards Committee tentative standard specifications for fire tests of building constructions and materials.[13] The temperature measurements of the furnace and the wall were made substantially as outlined in Section IV (pp. 76 to 78). The working loads applied in these tests were 120 lbs./in.^{2} of gross-bearing area for end-construction tile and 80 lbs./in.^{2} for side-construction tile.

Records were made of the character of the fire and its effect on the test wall during all stages of the test. After the fire exposure and after the walls had cooled the extent of the damage to the individual tiles was observed and recorded.

4. RESULTS OF TESTS

(a) EFFECT OF GROG ADDITIONS[14]

A series of tests was made to determine the effect of additions of grog (ground burned clay, usually broken or unmarketable tile) to the clay. For this study tile from three different kinds of clay, to each of which had been added 0, 2½, 5, and 10 per cent by volume of grog, were tested. The tile were 8 by 12 by 12 inch 6-cell end-construction tile manufactured especially for these tests, all conditions in each plant, such as drying and burning, being the same for each lot of tile. The tests consisted of subjecting walls of tile of the different amounts of grog content to fire exposure while under load of 120 lbs./in.^{2} The comparative fire resistance was determined by the length of time the walls were able to carry the working load, but no test was continued beyond six hours. The results are given in Table 4.

TABLE 4.—*Test durations of walls of tile containing grog*

Kind of clay used for tile	Grog content (per cent by volume)					
	0	2½	5		10	
	Hours	*Hours*	*Hr.*	*Min.*	*Hr.*	*Min.*
Shale	6	6	4	32	3	47
Fire clay	6	6	4	2	3	17
Shale and fire-clay mixture		6	4	50		20

From the table it is seen that the fire resistance decreases with increased grog content. The only reason that can be given for the earlier cracking of the tile and failure of the walls containing grog is the presence of minute cracks, probably from drying and burning shrinkage, radiating from the grog particles into the clay matrix.

[13] Appendix B, p. 326.

[14] "Effect of grog additions on fire resistance of hollow building tile," J. Am. Cer. Soc., **6**, No. 6, pp. 748-752, June, 1923.

It is concluded from these tests that small grog additions can be made without appreciable effect on the product, but that additions of 5 per cent or more will materially reduce the fire resistance.

(b) EFFECT OF COMBUSTIBLE FILLER ADDITIONS

A series of tests was made to determine the effect of adding to the clay during the process of manufacture a filler that will burn out when the tile are burned, leaving a porous body. Sawdust or lignite can be used for this purpose. Sawdust, being the most available, was used for this series of tests.

Tile from two shales, a fire clay and a surface clay having 0, 5, 10, and 15 per cent of sawdust (by volume), were made for these tests. All of the tile were of the 8 by 12 by 12 inch 6-cell end-construction design except those from one shale (*c–1*) which were 8 by 10¼ by 12 inch H-shaped side-construction units.

The effect on the fire resistance of the shale tiles was determined from the duration of the fire test with the walls under load, and the condition of the units after such test. The effect on the fire-clay and surface-clay tiles was determined by subjecting walls to a 1-hour fire exposure and then determining the strength of the individual units for comparison with the strength of the units not subjected to fire.

(1) TESTS WITH SHALE TILE.—The walls tested under load were able to carry the applied load for periods of from 2 hours 16 minutes to 6 hours or more, as given in Table 5, no test being extended beyond six hours.

TABLE 5.—*Test durations of walls of shale tile made of shale containing combustible filler*

Kind of clay	Per cent of sawdust filler (by volume)							
	0		5		10		15	
	Hours	*Hr.*	*Min.*	*Hours*	*Hr.*	*Min.*	*Hr.*	*Min.*
Shale *d*	6	1	39	6	2	16		
Shale *c–1*	6	6		6	3	40		

(2) TESTS WITH FIRE-CLAY AND SURFACE-CLAY TILE.—The percentage of loss in strength of the individual units due to the fire exposure was used to determine the effect of the filler on the fire resistance of the fire-clay and surface-clay tile. The percentage absorption of the tile not exposed to fire and the compressive strength, as computed on the net area of the original tile and comparable units after exposure to the test fire for one hour, are given in Table 6, where are also given the strength and absorption of the shale tiles not exposed to fire from the lot discussed in the previous paragraph.

TABLE 6.—*Strength and absorption of tile made of clays containing combustible filler*

Kind of clay		Per cent of sawdust filler (by volume)			
		0	5	10	15
Shale *d*:					
Strength	lbs./in.²	6,820	5,795	6,300	6,550
Absorption	per cent	8.5	10.9	13.0	14.9
Shale *e–l*:					
Strength	lbs./in.²	2,240	2,445	2,150	1,740
Absorption	per cent	12.7	14.3	16.7	19.5
Fire clay *m*:					
Absorption	do	7.3	5.6	9.1	10.4
Strength—					
Before fire	lbs./in.²	5,230	7,560	5,010	5,530
After fire	do	4,910	6,120	4,680	5,080
Loss	per cent	6.1	19.0	6.7	8.2
Surface clay *p–l*:					
Absorption	do	14.1	13.5	16.1	16.6
Strength—					
Before fire	lbs./in.²	2,870	3,060	2,870	2,470
After fire	do	2,570	2,700	2,420	2,250
Loss	per cent	10.3	11.7	15.5	8.9

The results of the tests can not be taken as fully conclusive, since it is not certain that comparable or representative conditions obtained in the manufacture of the units. The tile from a given plant were run through the same die and burned in the same kiln. The latter would probably result in harder burning for the tile made with the combustible filler, which may account in part for the shorter test durations given in Table 5 for tile with 5 to 15 per cent filler. However, all of these walls supported load for periods equal to or exceeding those determined by temperature transmission as given in Section IV of this paper.

The losses in strength of individual tile given in Table 6 are not considered serious from the standpoint of their effect on wall strength. It is seen that, before the fire, tiles made with filler were almost as strong as those without filler. Tile made with the higher filler contents developed less cracking than the harder tile, this being particularly marked for shale and dense-burning fire-clay tile. It was further indicated that the 15 per cent maximum amount of filler used was not the limit of what can be used without unduly decreasing the strength of the tile, although the higher resulting porosity would have to be considered where the tile are to be placed in outside walls.

Sawdust, with its relatively coarse grains, is probably not as well adapted for such purposes as finer material. Where coal is used as a filler the size of the grain is apparently important. In one fire test with tile made of clay mixed with about 25 per cent of granulated coal having particles up to the ⅛-inch size, failure with 2-cell 8 by 5 by 12 inch side-construction tile under 80 lbs./in.² load occurred 11 minutes after the fire was started. It is probable that weakening of the burned-clay body from shrinkage around the filler particles took place during the drying and initial portion of the burning period, similar to the effects produced by the grog filler (see (*a*) above).

(c) EFFECT OF FINENESS OF GRINDING OF THE CLAY

Tile from shale *d* and fire clay *l* were studied to determine the effect of the fineness of grinding of the clay material. Six-cell 8 by 12 by 12 inch end-construction tile, for which the clay had been ground to pass screens having openings of 0.14, 0.125, 0.10, and 0.070 inch, were manufactured for this work.

(1) SHALE.—The relative fire resistance of the shale tile was determined by the length of time walls of tile from each lot supported load under fire exposure. It was found that the wall from tile for which the clay was ground to pass 0.140-inch screen opening failed under load of 120 lbs./in.^{2} in 1 hour 38 minutes; that for which the clay was ground to pass 0.10-inch screen openings failed under this load in 1 hour 23 minutes; and that with tile of clay passing 0.070-inch openings carried this load up to the limit of the test, or 6 hours. Tile from shale ground to pass 0.125-inch screen openings were not included in this series.

(2) FIRE CLAY.—The relative fire resistance of the fire-clay tile was determined by subjecting unloaded walls to one-hour fire exposures and obtaining the loss in strength of the individual units. The procedure with shale tile described above was not followed, since failure under load within the six-hour test limit was not expected with walls built of this tile. The strength and absorption data for these tile, and also of the shale tile discussed under (1); are given in Table 7, the strength being computed for the net area.

TABLE 7.—*Strength and absorption of tile in the fineness of grinding series*

Kind of clay		Screen openings for clay (inches)			
		0.140	0.125	0.10	0.070
Shale *d*:					
Strength	lbs./in.^{2}	7,680	----------	12,860	11,190
Absorption	per cent	6.9	----------	5.6	6.2
Fire clay *l*:					
Absorption	per cent	9.7	10.0	10.4	10.7
Strength—					
Before fire	lbs./in.^{2}	5,210	4,950	6,240	6,040
After fire	lbs./in.^{2}	3,590	3,820	4,390	4,430
Loss	per cent	31.1	22.8	29.7	27.0

These strength tests and examination of the units after the fire tests showed that the susceptibility to cracking from fire exposure is not appreciably affected by the different degrees of grinding of the clay. However, higher tile strengths were generally obtained with the finer-ground materials, so that a wall of tile from the finer material would have a higher residual strength after fire exposure. It is concluded, therefore, that for load-bearing walls, increased or finer grinding increases the fire resistance of the wall only as it increases the strength of the tile. The minor irregularities in results can be attributed to difference in hardness of burning between tile in the different lots as indicated by the absorption.

(d) AMOUNT OF PUGGING OF THE CLAY

The value of increasing or decreasing the amount of pugging (mixing, working) of the clays before molding was studied with 6-cell 8 by 12 by 12 inch end-construction tile made from shale *d*, a dense-burning fire clay similar to *l* and *m*, and a surface clay *p*–1. All manufacturing conditions for each lot were maintained as constant as possible except for the amount of pugging, which was varied in the length of time the clay remained in the pug mill by three steps, from one-half the normal time to twice this time. The effect of the amount of pugging on the fire resistance was determined by subjecting walls to a one-hour fire exposure under no load and obtaining the percentage loss in strength of the individual units. The strength and absorption data are given in Table 8.

TABLE 8.—*Strength and absorption of tile in the pugging series*

Kind of clay		Amount of pugging		
		One-half	Normal	Double
Shale *d:*				
Absorption	per cent	6.4	5.5	5.8
Strength—				
Before fire	lbs/in.²	6,720	7,020	6,450
After fire	lbs/in.²	5,780	5,880	6,240
Loss	per cent	16.3	13.9	3.3
Dense-burning fire clay *m:*				
Absorption	per cent	8.0	8.2	7.5
Strength—				
Before fire	lbs/in.²	5,580	6,880	7,080
After fire	lbs/in.²	4,420	3,670	5,600
Loss	per cent	20.7	46.6	20.9
Surface clay *p-1:*				
Absorption	per cent	17.1	14.1	14.6
Strength—				
Before fire	lbs/in.²	2,710	2,870	2,780
After fire	lbs/in.²	2,380	2,570	2,580
Loss	per cent	12.2	10.3	7.2

As shown in the table, there is some increase in strength for the shale and fire clay with increased pugging in most cases, but none for the surface clay. For the latter there is also less loss in strength due to fire exposure with increased pugging. Examination of the individual units did not show an appreciable difference in fire effects with a change in amount of pugging. It is concluded, therefore, that increased pugging in common with finer grinding increases the fire resistance of load-bearing walls only as it increases the strength of the individual units, which means higher masonry strength during and after fire. In neither was it indicated that the gain in fire resistance obtainable by these methods would be very large.

(e) DESIGN OF UNIT

Several attempts were made to decrease the susceptibility of individual units to damage by making changes in the design of the unit. One change involved the use of curved transverse webs and

shells in the 6-cell 8 by 12 by 12 inch end-construction tile (see fig. 10). Results of four fire tests of walls of fire-clay tile from source *l* of this design, compared with those from tests of the standard 6-cell design with straight webs, showed decreased fire resistance for the modified design.

Another design involved the use of double side shells, the outer one being as thin as practicable and serving as a protection and the inner somewhat thicker and serving to carry the load. A tile of design similar to this (fig. 11 A) was being manufactured that had five short interior webs between the inner and outer shells. Tests of walls of tile of this design showed that the fire damage to the

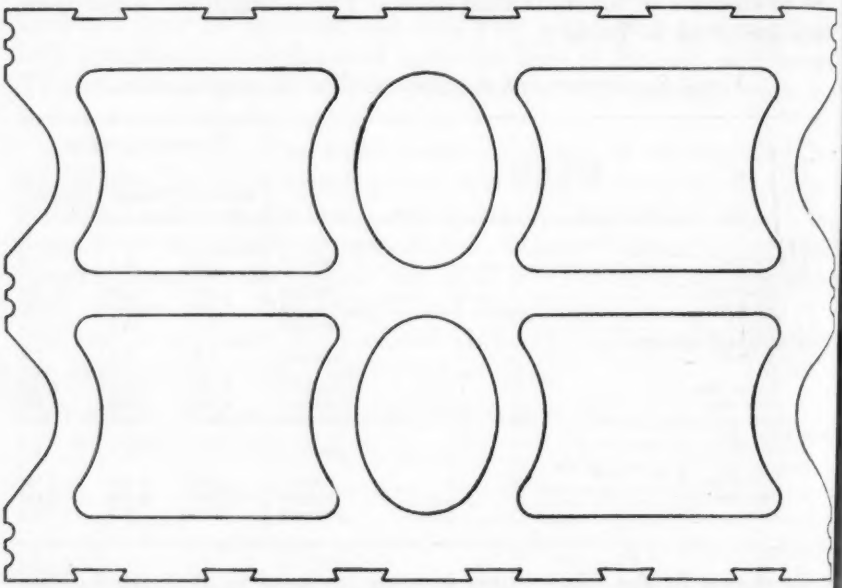


FIG. 10.—*Design of 8 by 12 by 12 inch experimental unit with curved transverse shells and webs*

units consisted mainly in the cracking or fracture of the long transverse webs, as shown in Figure 11 A. This design was modified by eliminating three of the short webs connecting the inner and outer side shells, as shown in Figure 11 B.

Three fire tests of fire-clay tile of this design from source *m* showed that most of the damage consisted in fracture of the short webs between the outer shells, although some cracks were found in the long webs back of the inner shell. Similar effects were shown in subsequent tests of large walls of double-shell tile from the same source (Nos. 89 and 90, p. 129). With walls of such tile, damage is confined mainly to portions near the exposed side, and repairs can be made by resetting any loose shells in mortar and replastering.

In this connection two tests were also made with shale tile from source *d*, the tile in one test having three of the seven short webs between inner and outer shell cut. With the seven full webs the fracture occurred back of the inner shell, the outer shell remaining connected with the inner shell. Where only four webs connected them the outer shell fell off after 25 or 30 minutes of fire exposure, thereby exposing the inner shell. The wall carried the 120 lbs./in.^{2} load during the one and one-half-hour test, but after cooling it failed before the full load was applied. It therefore appears that for tile particularly subject to fire damage this modified design gives no better results than the regular 6-cell design where the wall is not plastered. However, in a test of a large plastered wall of double-shell tile from this source (No. 15, p. 107), with only the four webs connecting outer and inner shells, the former remained in place

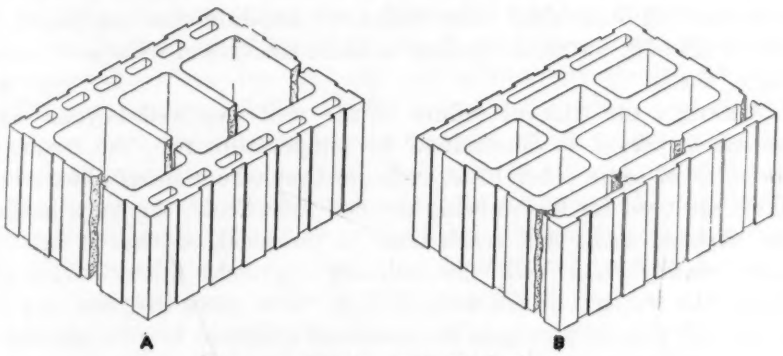


FIG. 11.—*Design of double-shell unit*

A, Original design of double-shell unit showing usual place of fracture of webs when exposed to fire
B, Improved design of double-shell unit showing usual place of fracture of webs when exposed to fire

except on a few vitrified tiles and afforded substantial protection for the rest of the wall.

(f) SHELL THICKNESS

Tests of shale tile from source *d* having shell thicknesses of ½, ¾, and 1 inch were made to study the effect of shell thickness. Two fire tests of 4 by 4 foot walls under 120 lbs./in.^{2} load were made, one being of tile having ¾-inch shells, which failed under the load after fire exposure of 3 hours 40 minutes, and the other of tile having 1-inch shells, which failed under the load at 5 hours 45 minutes. A test of a wall made of tile having ½-inch shells could not be made because of lack of material, as approximately 50 per cent of the units were broken in transit, although packed and handled the same as the tile having thicker shells, only few of which were damaged. These two tests indicate that the tile having the heavier shells are more fire resistant, although both walls carried the load beyond the normal resistance period of 8-inch walls as determined by the temperature rise on the unexposed side.

To determine the effect of shell thickness on the length of the fire exposure necessary to cause crackling of webs and loosening of shells, three tests of individual tile with each shell thickness were made. These indicated little difference between tile having ¾ and 1 inch shells, but that those having ½-inch shells were damaged in less time than tile with heavier shells.

(g) FILLETS

Tests of shale tile from source *d* having fillets of ¼, ½, and 1 inch radius were made to study the effect of the size of the fillets. Three fire tests of walls under 120 lbs./in.² load were made. The wall of tile having the standard fillets of ¼ to ⅜ inch radius failed under load after 3 hours 36 minutes, the one of tile having ½-inch fillets carried the load for the full six-hour test period, and the one of tile with 1-inch fillets failed under load after 2 hours 6 minutes. Short fire exposures of individual tiles indicated no difference ascribable to size of fillets in the time required to cause fracture of webs and loosening of shells.

Although the time of failure of the wall was well beyond their resistance period as determined by temperature rise, the results of these, as of some other tests, indicate that where small fillets or no fillets are used for tile showing decided fire effects, the webs holding the exposed shells will crack next to the shell, so that it falls off more readily than with the ordinary (¼-inch) fillets. With the latter, the fracture of the webs is likely to be more irregular and the shells will generally remain in place and continue to give protection for the duration of the fire. If large fillets are used, the minimum thickness of the web will be at its mid-point along which the fracture will occur, leaving the shell with less bond with the rest of the wall than where the web cracks are more irregular.

IV. FIRE TESTS OF TYPICAL HOLLOW-TILE WALLS

1. PURPOSE

The purpose of this series of tests is to determine the ultimate fire resistance afforded by various types and constructions of load-bearing hollow-tile walls and their behavior when suddenly cooled by water from the heated condition incident to fire exposure.

2. SCOPE OF TESTS

This series consists of 167 fire-endurance tests of load-bearing hollow-tile walls of the types and constructions in general use and four fire and water tests of walls built up of sections of the various kinds of tile subjected to the fire-endurance tests.

The tests were arranged to bring out the effects of such factors as type of clay used, design of the units, method of wall construction, application of plaster, number of cells, shells or units in a given wall

thickness, total thickness of wall, and amount of load or restraint applied during the tests. The material for these tests was obtained, generally in carload shipments, from the principal tile-producing centers.

(a) TYPES OF CLAY AND DETAILS OF MANUFACTURE

Three general types of clays are used in the manufacture of hollow tile, namely, shale, fire clay, and surface clay. The chemical analysis and softening points of the clays from which tile for these tests were made are given in Tables 1 and 2 (pp. 21 and 22).

The shales from which the tile used in this series of tests were made were of two grades, one being a true shale occurring as a stratified and consolidated mass. (Sources *a*, *a–1*, *d*, *d–1*, *d–2*, *d–3*). It burns to a dense hard body. The other was less compacted and could be dug with a steam shovel without the aid of blasting and be prepared for use with only a small amount of grinding (sources *c*, *c-1*). The tile from another semishale (*k–3*) exhibited more nearly the properties of surface-clay tile and are accordingly classed as such.

The surface clays can be divided into three grades. One (*k*, *k–1*, *k–2*) is a dark red-burning plastic material which generally gives a laminated product. The second (*p–1*, *r*) is an alluvial material with high softening point which burns to a light-red color. The maturing range of this material is wide. The third (sources *j*, *o–1*) comprised glacial clays which have a high lime content and burn to a salmon color. The maturing range of this material is narrow, and when it is slightly overburned fusion takes place. However, when properly burned the tile will be of uniform quality, although having a high absorption.

The fire clays from which the tiles used in this series were made can be placed in two grades. One (sources *f*, *l*, *l–1*, *l–2*, *m*), being impure fire clay occurring with coal measures chiefly in the Ohio soft-coal field. It burns to a light-buff color and a dense homogeneous body having medium to low percentage absorption. The other grade (sources *h*, *n*, *p*) includes transported material of a semi-refractory nature which burns to a range in buff colors and has often a laminated structure. It generally has a wide maturing range and gives tile of medium absorption.

Description of clay and methods of manufacture are given for the material from some of the sources in Section I of this paper (pp. 18 to 20). The following gives information from some of the additional sources represented in the present series:

Source a–1.—The raw material used in the manufacture of ware from this plant is a mixture of shale, soapstone, and fire clay. The shale in this mixture is a soft carboniferous substance, which is about 22 feet thick and overlies about 3 feet of soapstone, which is also included in the mixture. The soapstone is a very hard material and not a true soapstone in the geological sense, but rather a

term applied to this formation throughout this part of the country. We have a stratum of coal running from 20 to 26 inches thick. Underneath this we have a deposit of from 6 to 12 feet of No. 2 fire clay.

The work necessary for preparing the raw material for the auger machine is as follows: The shale is dug by a shale planer, which gives us a perfect mixture of the raw material from the top to the bottom of the bank. The coal and fire clay are dug separately, and merely the shale and soapstone are mixed by this machine. The coal is excluded from the mixture entirely and fire clay is added in the grinding department. The clay is brought in by means of electric haulage to the factory, where it is ground and mixed with fire clay, then screened through ⅛-inch screen. It is then put into a reserve bin for use at the auger machine. At this plant we are employing exhaust steam 10 hours per day and live steam 14 hours per day for drying. The drying period for this ware is 48 hours.

The burning process consists of water smoking, oxidation, and finishing. After the ware is put into the kiln, the heat is brought up slowly and carried at about 300° F. until all the free water is expelled. We then raise the heat gradually to expel the combined water. This period runs up to about 1,000° F., and then the oxidation period commences and is carried on until all the carbon, sulphur, and other chemicals that must be driven off are expelled. The heat is then raised again for a maturing temperature, which at this factory is approximately 1,800° F. The difference in temperature between the top and bottom of kilns varies from 100 to 250° F.

The clay in this section of the country is impregnated with iron pyrites, which, if not mechanically separated or finely ground during the process, causes the ware to flake during the burning period. This is no detriment to the strength of the block, and we would also further state that no further flaking will occur after the ware is out of the kilns. The point we would like to bring out here is the fact that this pyrite does not act in the same way that lime acts. Lime will not show up in burning to any great extent, but after the ware is subjected to weather conditions it starts to pop and may damage the ware so badly that it would affect its compressive strength. Pyrites does not act this way, and all the damage is visible when the ware is taken from the kilns.

Source l–1.—The tile are manufactured of blue shale.[15] This shale is taken from our pit, which has an overburden of 12 feet and a strata of blue shale underneath of 20 feet. This shale is soft and the only operation for preparing it for the machine is running it through the pans and over the screen. It is then ready to pass through the auger machine.

The tile, after passing through the auger machine, moves to a steam drier, where it is thoroughly dried. The drying operation takes from four to eight hours. It is burned in down-draft kilns, the process taking from four to six days, the average maturing temperature being approximately 1,900° F.

Source l–2.—We use an impure fire clay of a siliceous nature which fuses at cone 27 (1,600° C., 2,912° F.). It is a sedimentary clay, the thickness of the seam being 20 feet. It is mined by the open-quarry method, ground in dry pans, and tempered about three minutes in the pug mill. The drying is done in an ordinary progressive waste-heat drier in 48 hours with a maximum temperature of 250° F. The tile are burned in down-draft kilns in four days with a maximum temperature of 2,100° F. The range in temperature between top and bottom of kiln is 60° F.

Source k–3.—The raw material is a semisoft shale dug with a shovel from a 60-foot bank. It is dumped into a granulator, then into a disintegrator, and passed through two conical rolls, a 12-foot pug mill, and a combination (pug-

[15] Actually a very dense burning fire clay.

auger) machine. The tile are dried in a Proctor drier for 15 hours at 170° F., and burned in up-draft continuous kilns for seven days at a maximum temperature of 1,850° F. There is little difference in temperature between top and bottom of kiln.

Source o–1.—The clay is a surface clay occurring in an alluvial deposit 45 feet thick and is dug with a power shovel. It is passed through a 12-foot granulator, a 16-foot pug mill, and smooth conical rolls. The tile are dried in a waste-heat drier for 72 hours at 180° F. The tile are burned in round down-draft kilns for 96 hours at a maximum temperature of 1,700° F., the temperature difference between top and bottom of kiln being about 30° F. The clay is very fine grained and requires slow drying and water smoking. It has a very short vitrification range.

Source r.—The raw material from which our tile is made is composed of a mixture of plastic stoneware clay, fire clay, and fire sand. This fire clay and stoneware clay are found at a depth of from 15 to 40 feet below the surface in a plastic form. The method of mining is first to remove the top surface of dirt, stones, and other refuse with steam shovels until the strata of clay is uncovered. The clay is then dug out by hand with ordinary clay spades and loaded by hand into cars for transportation to the machine department.

The first preparation of this clay is made by running it through a clay cleaner which removes all stones and separates the clay into small particles. The proper mixture of the two clays and sand are put into a pug mill and properly tempered with water. From this pug mill the material is run into another pug mill and after the second pugging, which completes the preparation, the clay is transmitted by conveyor belts to the machines and formed into proper shapes. From the machines they are transported in a vertical position on small steel drier cars into a steam drier, where they are dried from 60 to 72 hours.

From the driers they are carried on the same cars to the kilns, which are of the round down-draft type, and loaded into the kilns by hand, and are then burned by gradually bringing the heat up to a maximum temperature of from 1,800 to 2,000° F. This process takes from four to five days. The difference in temperature between the bottom and top of the kilns during the process of burning would be from 75 to 125° F. After the burning is finished, the tops of the kilns and doors are opened gradually until the process of cooling is completed, which takes 60 to 72 hours.

(b) DESIGN OF UNITS

(1) NOTATION.—As an aid in distinguishing the different designs of units and walls, a method of designation was adopted consisting first, of a number to designate the wall thickness; second, of a letter to designate the design or designs of the tile used; third, of the letters "E" or "S" to designate the main type of construction used. The cross sections of the tile designs are given in Figure 13. Thus 8–A–E designates an 8-inch wall of 6-cell 8 by 12 by 12 inch tile, set with cells vertical.

(2) DESCRIPTION OF TYPICAL DESIGNS.—All of the typical designs of units in common use were included in these tests. The 6-cell 8 by 12 by 12 inch end-construction unit (fig. 13, A) was generally used in the comparative tests made to determine the effect of nearly all variables except design.

Hollow tile, from the standpoint of application, may be divided into two classes—end construction and side construction. End-construction tile [16] is designed to receive its principal stress parallel to the direction of its cells, which for load-bearing walls requires that it be set with its cells vertical. Three main designs of end-construction tile were included in these tests. One (fig. 12*a*, type 8–A–E, and fig. 13, A) is the 6-cell 8 by 12 by 12 inch unit with transverse webs spaced at approximately equal distances apart, so that the cells are nearly equal in size. With this design the longitudinal shells and webs are always in alignment with superimposed units, but the transverse webs are seldom in alignment. In the second design (fig. 12*a*, type 8–B–E, and fig. 13, B) of 8 by 12 by 12 inch end-construction units the two transverse webs are placed from ½ to 1 inch apart, so that four equal cells are formed in the corners of the unit and two smaller equal cells in the middle. By proper placement of the units in the wall the transverse shells and webs will be in alignment with those of superimposed units. The third design (fig. 12*c*, type 8–D–E, and fig. 13, D) is the double-shell unit designed to provide better mortar bedding, insulation, and fire resistance.

Although end-construction tile should always be set with cells vertical in order to obtain maximum strength,[17] inexperienced mechanics often lay them with cells horizontal. Hence some tests of end-construction tile laid on side were included.

Side-construction tile [18] is designed to receive its principal stress perpendicular to the direction of its cells, which requires for load-bearing walls that it be laid with its cells horizontal. Five general designs of side-construction tile and some additional special shapes were used in the tests. The first design (fig. 12*b*, type 8–K–S, and fig. 13, K) was the 3-cell 8 by 5 by 12 inch unit with all cells equal. The second design (fig. 13, L) was the 2-cell 8 by 5 by 12 inch unit having one center vertical web. The third design (fig. 12, B, type 8–O–S, and fig. 13, O) was the T-shaped (interlocking) 8 by 6¼ by 12 inch unit. With the latter properly laid, units of the same size can be used for walls of different thicknesses. The horizontal mortar beds are broken so as to be at different levels at points in the wall thickness. This design gives three cells through the thickness of 8-inch walls. The fourth design (fig. 12, C, type 8–P–S, and fig. 13, P) was the H-shaped 8 by 10¼ by 12 inch unit. This is designed so that it can be split and used for walls of thicknesses which are multiples of 4 inches. It is also possible to insert insulating pads in walls built of units of this design. The fifth design (fig. 12*b*, type 8–Q–S, and fig. 13, Q) was the 9-cell cube-shaped 8 by 8 by 8 inch unit. This unit is designed so that it can be laid on any of the four

[16] Appendix A, p. 324.
[17] Tech. Paper No. 311, Compressive and Transverse Strength of Hollow Tile Walls.
[18] Appendix A, p. 324.

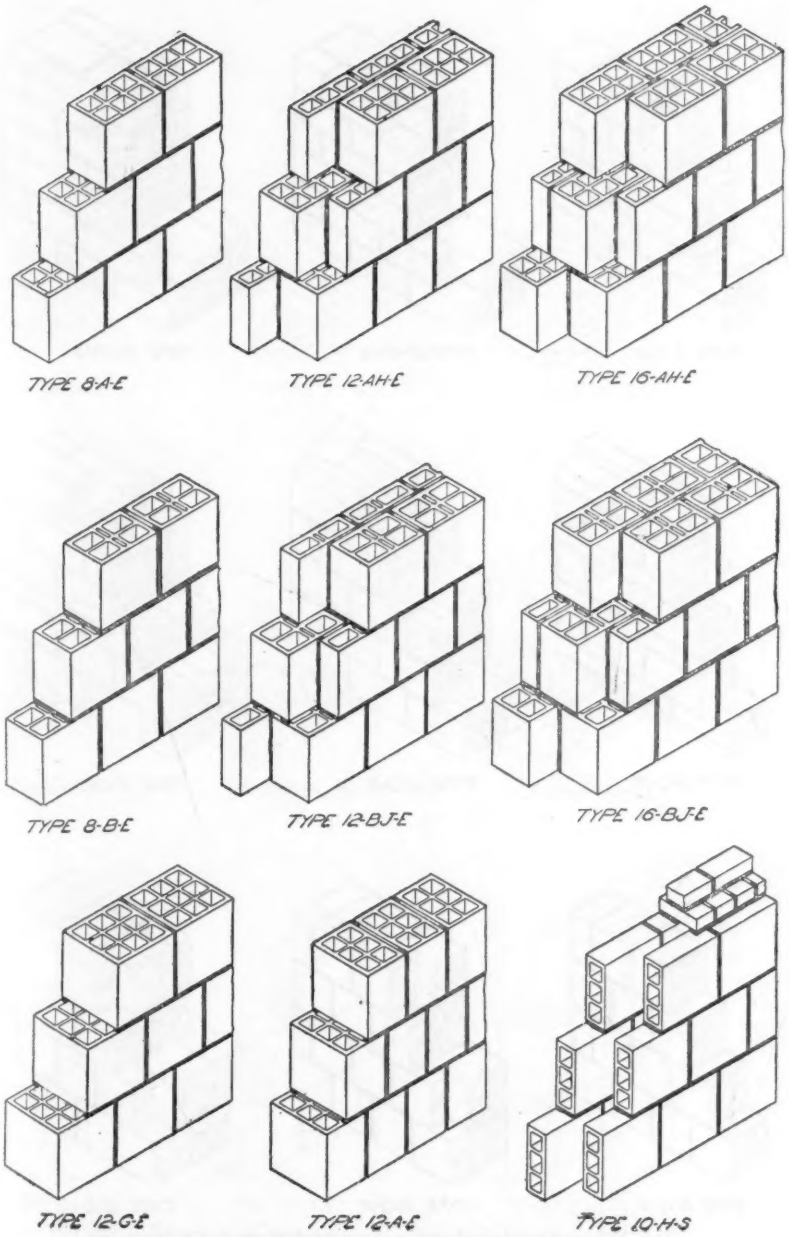


FIG. 12a.—*Sketches showing some typical wall constructions*

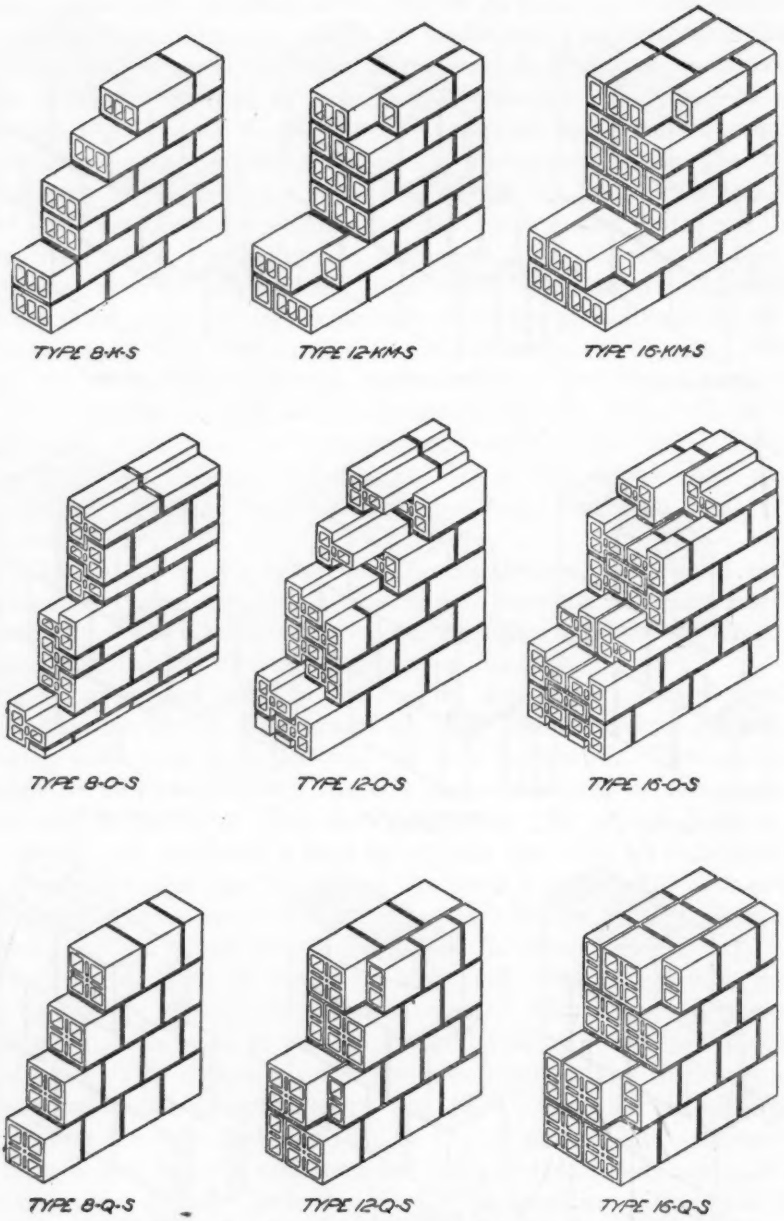


FIG. 12b.—*Sketches showing some typical wall constructions*

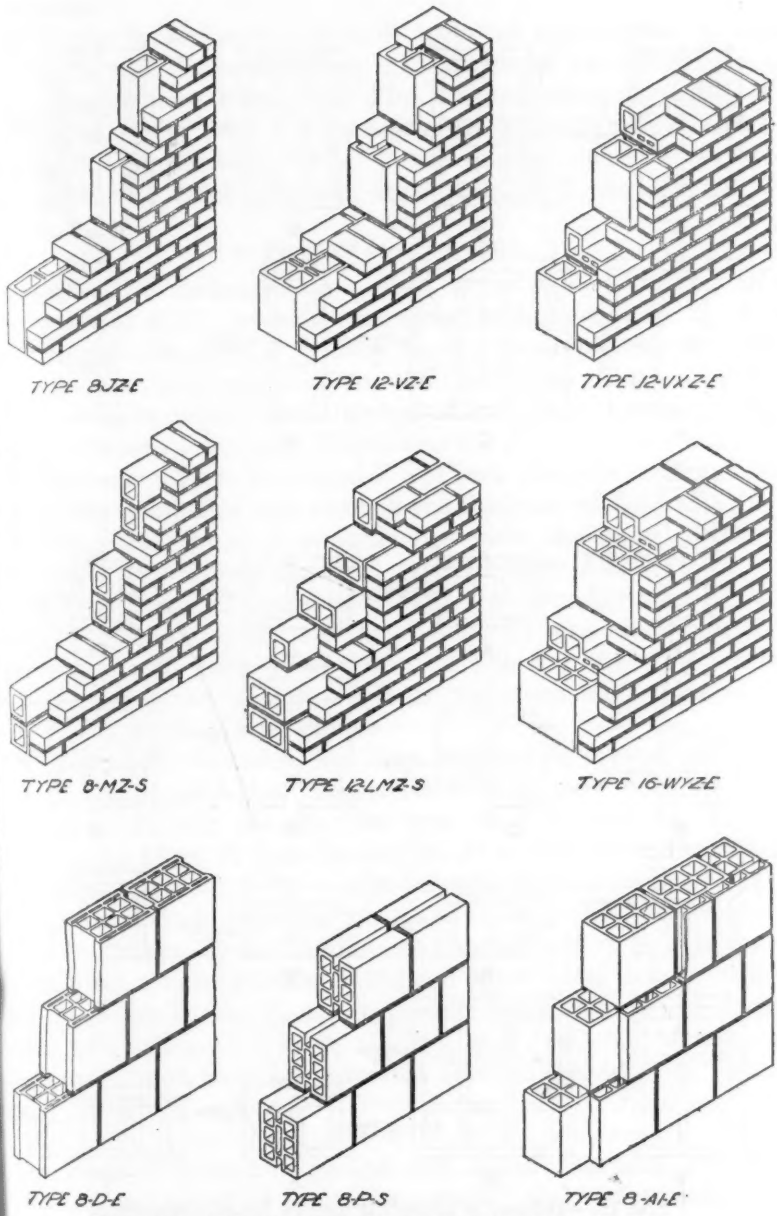


FIG. 12c.—*Sketches showing some typical wall constructions*

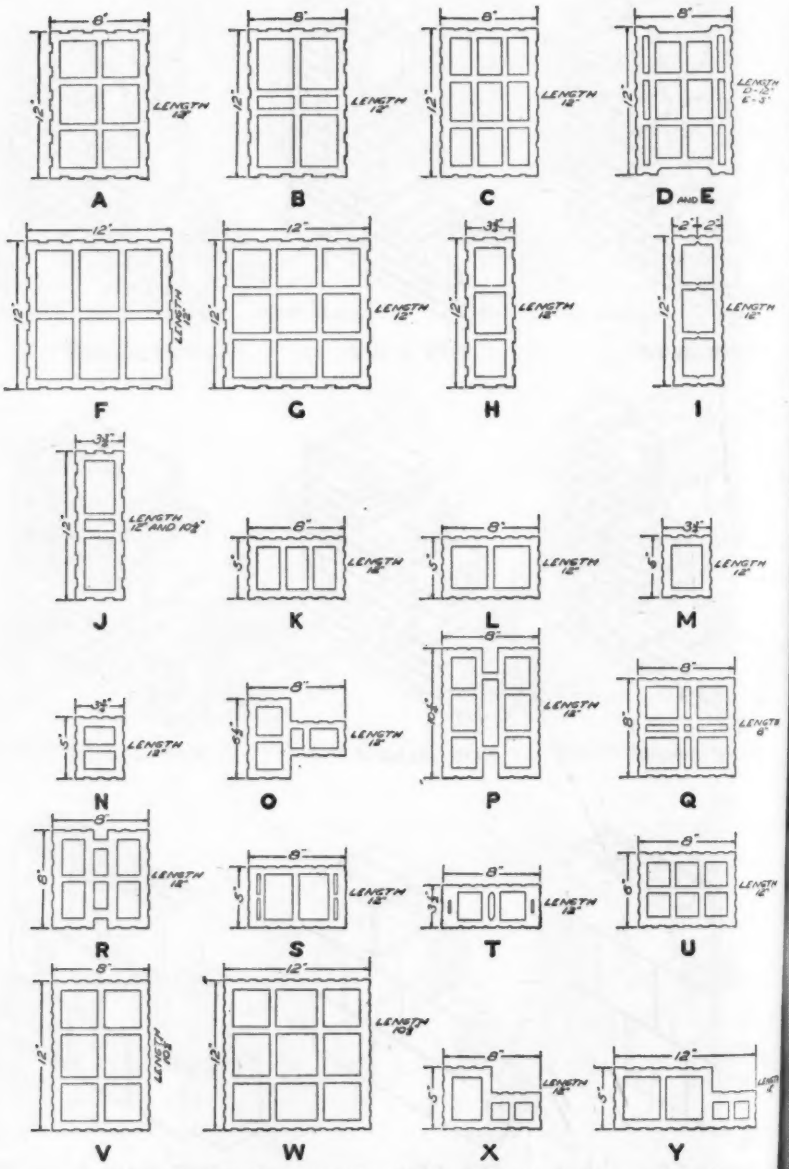


FIG. 13.—*Designs of hollow tile used in fire-endurance tests*

sides for side construction or faced in any direction for end construction. It can also be split and used to form walls of different thicknesses.

All of the side-construction units included are designed so that they can be used for backing face brick. Several walls with units of these designs were tested (fig. 12c). Some end-construction tile cut to a length of 10½ inches were used in combination with L-shaped side-construction units (header-backer construction) for walls faced with brick (fig. 12*c*, type 12–VXZ–E, and figs. 13, V and 13, X).

(c) TYPES OF CONSTRUCTION

As previously indicated, two main types of construction were used, end and side. As end construction with 6-cell 8 by 12 by 12 inch tile (fig. 12*a*, type 8–A–E) is most commonly used for load-bearing tile walls, it was used for the tests made to determine the effects of all variables except design of units and number of cells through the wall thickness. The 2 and the 3 cell 8 by 5 by 12 inch side-construction units were used in the tests made to determine the effect of the number of cells through the thickness of the wall.

A few special types of constructions were also tested. One of these was a double wall (fig. 12*c*, type 10–H–S) consisting of two 4-inch walls spaced 2 inches apart and tied together with ¼-inch metal ties. Another (fig. 12*c*, type 8–AI–E) was an 8-inch end-construction wall furred with 2-inch split furring tile,[19] the furring tile being tied to the main wall with cut nails, one nail being used for every 4 square feet of wall surface.

The preceding discussion has been confined to typical units and walls of 8-inch thickness. Twelve-inch walls were built of 9-cell 12 by 12 by 12 inch tile (fig. 12*a*, type 12–G–E, and fig. 13, G). Six-cell 12 by 12 by 12 inch tile (fig. 13, F) is designed so that where properly set there will be three cells through the wall thickness. The 8 by 12 by 12 inch unit (fig. 13, A) can also be used as shown in Figure 12*a*, type 12–A–E, although giving only a 4-inch longitudinal bond. Combinations of 3¾ and 8 inch units to form 12-inch walls are shown in Figure 12*a*, types 12–AH–E and 12–BJ–E, and Figure 12*b*, types 12–KM–S, 12–O–S, and 12–Q–S. Methods of laying up 16-inch walls are apparent from the sketches in Figures 12*a*, 12*b*, and 12*c*.

(d) PLASTER

The kinds of plaster in general use, namely, cement, lime, and gypsum, were applied on some of the walls. Only a few walls, Nos. 50 to 55, were plastered with lime plaster. The tests of these walls were made early in the investigation, and as it was found that lime plaster would fall off during the first part of the test, its use was

[19] Appendix A, p. 324.

discontinued. Hence, for the tests made to determine the protection afforded by the plaster, a Portland cement or gypsum plaster of 1:3 volume proportions of binder and sand was used on either the exposed or both the exposed and the unexposed sides of the walls.

With the exception of a few of the early tests, all of the plaster was applied as two-coat work, the second or brown coat being applied as soon as the scratch coat had its initial set. The brown coat was troweled smooth and given a "sand float" finish. The third or white coat was not applied except for a few of the early tests, as this coat was considered mainly decorative, and essentially the same fire resistance would obtain with an equivalent thickness applied in two coats. For one test (No. 56) a one-coat cement plaster was applied and in another (No. 58) one body coat of gypsum plaster plus a white finish coat. Unless otherwise noted in Tables 9, 15, and 17, the plaster was applied in two body coats.

The average thickness of plaster consisting of two body coats ranged between five-eighths and seven-eighths inch for the different walls, the average for the plastered walls being probably near three-fourths inch. For three-coat work the thickness was one-eighth to three-sixteenths inch heavier, and for one coat or one coat and finish the total thickness was about one-half inch.

3. PROGRAM OF TESTS

The original program consisted of 45 fire-endurance tests and 4 fire and water tests of walls 10⅓ or 11 feet high and 16 feet wide. Tile from eight different plants were included in these tests. Two of these plants use typical shales; two, dense-burning fire clays; one, an open-burning fire clay; and three, typical surface clays. The fire exposures in the fire-endurance tests were to be continued until failure of the wall from load, deflection, or damage to the exposed units was obtained, with six hours as the limit of fire exposure.

An analysis of the results of a portion of this program which had been completed showed that the scope of the tests was not broad enough, in that tile from a larger number of plants and of other designs should be included. The method of measuring temperatures on the unexposed side under small asbestos pads had recently been adopted as standard, and it was deemed desirable to repeat some of the tests using the new method in order to obtain comparisons with temperature readings taken on the free surface and under the large cotton and excelsior pads.

To include tests covering all of these factors and to develop the full range of fire resistance of the heavier walls, it was necessary to add a considerable number of tests. Because of the large number of tests and also due to the necessity of continuing some of the tests of the heavier walls longer than six hours, which was near the limit

attainable in the large furnace, it was necessary to make many of these tests with the smaller furnace described in Section III of this paper.

Previous tests had shown that, except where failure was caused by lateral deflection or by spalling and falling of shells or plaster, the 4 by 4 foot walls would give nearly as reliable information as the larger walls. As deflections were moderate and shells and plaster remained in place in all but a few tests in the large furnace, the smaller size of test wall was available for a considerable portion of the work. It also appears that the 8-foot wide and 10⅓-foot high wall was satisfactory where load was applied. The walls of this size were obtained by building the larger wall with a continuous vertical joint, open from 2 to 4 inches at the center of the wall. In this way any special features embodied in one section did not affect the behavior of the other section, and both sections, which often embodied design or application features to be compared, were subjected to nearly the same fire exposure.

The complete program consisted of 167 fire-endurance tests and 4 fire and water tests. Of the fire-endurance tests, 113 were made on 8-inch walls, 36 on 12-inch walls, and 18 on 16-inch walls.

(a) FIRE-ENDURANCE TESTS

The fire-endurance tests are arranged (Table 9) with respect to (1) wall thickness, (2) kind of clay, (3) design of the unit, and (4) type of construction used. Where tests were made to determine the fire resistance of plastered in comparison with unplastered walls, the test of the plastered wall appears on the program immediately after the test of the comparable unplastered wall.

The details of the 8-inch walls of shale tile (Nos. 1 to 31, inclusive) are given in Table 9(*a*). Three of these were retests of walls that had been repaired by filling the cells next to the exposed side with a mortar of fluid consistency and plastering.

The details of the 8-inch surface-clay tile walls (Nos. 32 to 66, inclusive), a total of 35, are given in Table 9(*b*). For 28 of them end-construction tile, mostly 6-cell 8 by 12 by 12 inches, were used.

The details of the 8-inch walls of fire-clay tile, a total of 47, are given in Table 9(*c*). The large number of walls of this type of material is due to the fact that they include the comparative tests made to determine the effect of design of unit and of laying end-construction tile on side.

The details of the 12-inch walls (Nos. 114 to 147, inclusive) are given in Tables 9 (*d*), (*e*), and (*f*). This group includes tile from all typical clays and also some walls that were faced with brick.

The 16-inch walls (Nos. 148 to 164, inclusive) are listed in Tables 9 (*g*), (*h*), and (*i*). All but five of these walls were tested in the

small furnace, as it was necessary to continue the fire exposure for periods longer than six hours to obtain the limiting temperature rise on the unexposed surface.

The four tests that are marked "a" in Table 9 were supplementary tests of walls dried to constant weight prior to testing and were included in order to determine, by comparison with results of previous tests, the effect of the moisture remaining in walls which have aged for the usual 30 to 60 day period before testing. The presence of free water increases the effective heat capacity of the wall and, therefore, the time required to reach the limiting temperature rise on the unexposed surface.

(b) FIRE AND WATER TESTS

The details of the fire and water tests are given in Table 10. Sections of the two main types of construction and of the principal kinds of tile were included in each of these walls. The sections were arranged in three courses (see figs. 53, 54, 55, pp. 152 to 154), with four sections in each course. They were numbered on the exposed side from the left to right, beginning with the top course.

TABLE 9.—*Program of fire-endurance tests*

(*a*) 8-INCH WALLS OF SHALE TILE

Wall			Tile units			Number of cells or special design	Plaster [1]		Restraint or load
No.	Type	Size (feet)	Source	Design	Size (inches)		Exposed side	Unexposed side	
									Lbs./in.[2]
1	8-A-E	4 by 4	*d*	A	8 by 12 by 12	6	None	None	120
2	do	8 by 10⅓	*d*	A	do	6	do	do	120
3	do	do	*d*	A	do	6	do	do	120
4	do	16 by 10⅓	*d*	A	do	6	do	do	80
5	do	do	*d*	A	do	6	Gunite 1 : ½ : 3	do	80
6	do	16 by 11	*d*	A	do	6	None	do	Unrestrained.
7	do	4 by 4	*a–1*	A	do	6	do	do	120
8	8-A-S	8 by 10⅓	*d*	A	do	6	Gypsum	do	80
9	8-A-E	do	*d*	A	do	6	do	Gypsum	80
10	do	do	*d*	A	do	6	do	do	80
11	do	4 by 4	*d*	A	do	6	None	None	Restrained.
12	do	do	*d*	A	do	6	Gypsum [2]	Gypsum [2]	Restrained.
13	8-AI-E	do	*d*	A	8 by 12 by 12	6	do	do	Restrained.
				I	2 by 12 by 12	Furring			
14	do	do	*d*	A	8 by 12 by 12	6	do	do	Restrained.
				I	2 by 12 by 12	Furring			
15	8-E-E	8 by 10⅓	*d*	E	8 by 12 by 5	Double shell	do	do	80
16	do	do	*d*	E	do	do	do	do	80
17	8-K-S	4 by 4	*c*	K	8 by 5 by 12	3	None	None	80
18	8-L-S	do	*d–3*	L	do	2	do	do	80
19	8-O-S	do	*d–1*	O	8 by 6¼ by 12	T-shaped	do	do	80
20	do	do	*d–1*	O	do	do	do	do	80
21	do	8 by 10⅓	*d–1*	O	do	do	do	do	80
22	8-P-S	4 by 4	*c–1*	P	8 by 10¼ by 12	H-shaped	do	do	80
23	do	do	*c–1*	P	do	do	do	do	80
24	8-Q-S	do	*d*	Q	8 by 8 by 8	9	do	do	80
25	do	8 by 10⅓	*d*	Q	do	9	Gypsum	do	80
26	8-R-S	4 by 4	*a*	R	8 by 8 by 12	H-shaped	None	do	80
27	do	do	*a*	R	do	do	Gypsum	do	80
28	8-T-S	do	*d–3*	T	8 by 3½ by 12	3	None	do	80
29	do	do	*d–3*	T	do	3	Gypsum	do	80
30	8-S-S	do	*d–3*	S	8 by 5 by 12	2	None	do	80
31	do	do	*d–3*	S	do	2	Gypsum	do	80

[1] All plaster 1:3 volume parts calcined gypsum, Portland cement, or hydrated lime, and sand, applied in two body coats, unless otherwise indicated.
[2] Two coats 1:3 plaster plus finish coat of 1:1 lime, putty, and calcined gypsum.

TABLE 9.—*Program of fire-endurance tests*—Continued

(*b*) 8-INCH WALLS OF SURFACE CLAY TILE

Wall			Tile units			Number of cells or special design	Plaster		Restraint or load
No.	Type	Size (feet)	Source	Design	Size (inches)		Exposed side	Unexposed side	
									Lbs./in.[3]
32	8-A-E	4 by 4	*j*	A	8 by 12 by 12	6	None	None	120
33	do	do	*j*	A	do	6	do	do	120
34	8-C-E	8 by 10⅓	*j*	C	do	9	do	do	120
35	do	do	*j*	C	do	9	do	do	120
36	do	8 by 11	*j*	C	do	9	Gypsum	do	Restrained.
37	do	do	*j*	C	do	9	Cement	Cement	Restrained.
38	do	8 by 10⅓	*j*	C	do	9	None	None	70
39	do	do	*j*	C	do	9	Gypsum	do	70
40	8-A-E	4 by 4	*r*	A	do	6	None	do	120
41	do	do	*r*	A	do	6	do	do	120
42	8-B-E	16 by 11	*k*	B	do	6	do	do	Unrestrained.
43	do	8 by 10⅓	*k*	B	do	6	do	do	120
44	do	do	*k*	B	do	6	do	do	120
45	do	8 by 11	*k*	B	do	6	Gypsum	do	Restrained.
46	do	do	*k*	B	do	6	Cement 1:3 plus 15 per cent lime.	Cement 1:3 plus 15 per cent lime.	Restrained.
47	do	4 by 4	*k*	B	do	6	None	None	Restrained.
48	do	do	*k*	B	do	6	Cement 1:2½	Cement 1:2½	Restrained.
49	do	do	*k*	B	do	6	Gypsum [2]	Gypsum [2]	Restrained.
50	do	do	*k*	B	do	6	Lime	Lime	Restrained.
51	do	do	*k*	B	do	6	Cement-lime 1:½ : 4	None	Restrained.
52	do	do	*k*	B	do	6	Cement-lime 1:1:5	do	Restrained.
53	do	do	*k*	B	do	6	Cement-lime 1:2:7	do	Restrained.
54	do	do	*k*	B	do	6	Lime	do	Restrained.
55	do	do	*k*	B	do	6	do	do	Restrained.
56	do	do	*k*	B	do	6	Cement 1:2½ [3]	do	Restrained.
57	do	do	*k*	B	do	6	Cement 1:3 plus 15 per cent lime.	do	Restrained.
58	do	do	*k*	B	do	6	Gypsum [4]	do	Restrained.
59	do	do	*k*	B	do	6	do [5]	do	Restrained.
60	8-O-S	8 by 10⅓	*p-1*	O	8 by 6¼ by 12	T-shaped	None	do	80
61	8-K-S	4 by 4	*o-1*	K	8 by 5 by 12	3	do	do	80
62	8-L-S	do	*k-1*	L	do	2	do	do	
63	do	do	*k-3*	L	do	2	do	do	
64	8-U-S	do	*k-2*	U	do	2	do	do	

62	8-L-S	do	*k-1*	L	do	2	do	do		80
63	do	do	*k-3*	L	do	2	do	do		80
64	8-U-S	do	*k-2*	U	8 by 6 by 12	6	do	do		80
65	8-O-S	do	*r*	O	8 by 6¼ by 12	T-shaped	do	do		80
66	do	do	*r*	O	do	do	do	do		80

(c) 8-INCH WALLS OF FIRE CLAY TILE

67	8-A-E	16 by 11	*n*	A	8 by 12 by 12	6	None	None	Unrestrained.
68	do	do	*n*	A	do	6	Gypsum	Gypsum	Restrained.
69	do	8 by 10½	*n*	A	do	6	None	None	120
70	do	do	*n*	A	do	6	Gypsum	Gypsum	120
71	do	8 by 11	*n*	A	do	6	None	None	Restrained.
72	do	do	*n*	A	do	6	Gypsum	Gypsum	Restrained.
73	do	4 by 4	*l*	A	do	6	None	None	120
[6]73a	do	do	*l*	A	do	6	do	do	120
74	do	8 by 10½	*l*	A	do	6	do	do	120
75	do	do	*l*	A	do	6	do	do	120
76	do	16 by 11	*l*	A	do	6	do	do	Restrained.
77	do	8 by 11	*l*	A	do	6	Gypsum	do	Restrained.
78	do	do	*l*	A	do	6	Cement 1:3 plus 15 per cent lime.	do	Restrained.
79	8-A-S	8 by 10½	*l*	A	do	6	None	do	80
80	do	do	*l*	A	do	6	Gypsum	Gypsum	80
81	do	8 by 11	*l*	A	do	6	None	None	Restrained.
82	do	do	*l*	A	do	6	Gypsum	Gypsum	Restrained.
83	8-B-E	4 by 4	*m*	B	do	6	None	None	Restrained.
84	do	do	*m*	B	do	6	Gypsum [2]	Gypsum [2]	Restrained.
85	do	8 by 11	*m*	B	do	6	Cement 1:3 plus 15 per cent lime.	None	Restrained.
86	do	do	*m*	B	do	6	Gypsum	Gypsum	Restrained.
87	do	do	*m*	B	do	6	do	do	Restrained.
88	8-BI-E	do	*m*	B	8 by 12 by 12	6	do	None	Restrained.
				I	2 by 12 by 12	Furring			
89	8-D-E	do	*m*	D	8 by 12 by 12	Double-shell	None	do	Restrained.
90	do	do	*m*	D	do	do	Gypsum	Gypsum	Restrained.
91	8-E-E [7]	4 by 4	*m*	E	8 by 12 by 5	do	None	None	120
92	do [7]	do	*m*	E	do	do	do	do	120
93	do [7]	do	*m*	E	do	do	do	do	120
94	8-K-S	do	*h*	K	8 by 5 by 12	3	do	do	80
95	do	8 by 11	*m*	K	do	3	do	do	Unrestrained.

[2] Two coats 1:3 plaster plus finish coat of 1:1 lime, putty, and calcined gypsum.
[3] One coat.
[4] One coat 1:3 plaster plus finish coat of plastic gypsum.
[5] Two coats 1:3 plaster plus finish coat of plastic gypsum.
[6] Was dried to nearly constant weight before testing.
[7] Old design of units. See *A*, Figure 11. Some were 10 inches long.

TABLE 9.—*Program of fire-endurance tests*—Continued

(*c*) 8-INCH WALLS OF FIRE CLAY TILE—Continued

Wall			Tile units			Number of cells or special design	Plaster		Restraint or load
No.	Type	Size (feet)	Source	Design	Size (inches)		Exposed side	Unexposed side	
									Lbs./in.[3]
96	8-K-S	8 by 11	*m*	K	8 by 5 by 12	3	Gypsum	Gypsum	Restrained.
97	8-L-S	do	*m*	L	do	2	None	None	Unrestrained.
98	do	do	*m*	L	do	2	Gypsum	Gypsum	Restrained.
99	8-K-S	4 by 4	*l-2*	K	do	3	None	None	80
101	8-O-S	do	*l-1*	O	8 by 6¼ by 12	T-shaped	do	do	80
102	do	do	*l-1*	O	do	do	do	do	80
103	8-P-S	do	*l*	P	8 by 10¼ by 12	H-shaped	do	do	80
104	do	do	*l*	P	do	do	do	do	80
105	do	8 by 11	*l*	P	do	do	do	do	Restrained.
106	do	do	*l*	P	do	do	Gypsum	Gypsum	Restrained.
107	8-Q-S	4 by 4	*f*	Q	8 by 8 by 8	9	None	None	80
108	do	do	*f*	Q	do	9	Gypsum	Gypsum	80
109	8-Q-E	do	*f*	Q	do	9	do	do	120
110	10-H-S	8 by 10⅓	*l*	H	3¾ by 12 by 12	3	do	Cement 1:3 plus 15 per cent lime.	110
111	10-N-S	do	*l*	N	3¾ by 5 by 12	2	do	do	110
112	8-MZ-S	do	*m*	M	do	1	Gypsum	Brick	80
				Z	2¼ by 3¾ by 8	Brick			
113	8-JZ-E	do	*m*	J	3¾ by 12 by 10½	3	do	do	80
				Z	2¼ by 3¾ by 8	Brick			

(*d*) 12-INCH WALLS OF SHALE TILE

114	12-A-E	4 by 4	*d*	A	8 by 12 by 12	6	None	None	120
115	do	do	*d*	A	do	6	do	do	120
116	12-AH-E	do	*d*	A	do	6	do	do	120
				H	3¾ by 12 by 12	3			
117	do	do	*d*	A	8 by 12 by 12	6	do	do	120
				H	3¾ by 12 by 12	3			
118	12-O-S	8 by 10⅓	*d-1*	O	8 by 6¼ by 12	T-shaped	do	do	80

(*e*) 12-INCH WALLS OF SURFACE CLAY TILE

(e) 12-INCH WALLS OF SURFACE CLAY TILE

119	12-C-E	4 by 4	*j*	C	8 by 12 by 12	9	None	None	120
120	12-CH-E	do	*j*	C	do	9	do	do	80
				H	3¾ by 12 by 12	3			
121	do	do	*j*	C	8 by 12 by 12	9	do	do	80
				H	3¾ by 12 by 12	3			
122	do	do	*j*	C	8 by 12 by 12	9	do	do	80
				H	3¾ by 12 by 12	3			
123	do	8 by 10½	*j*	C	8 by 12 by 12	9	do	do	80
				H	3¾ by 12 by 12	3			
124	12-BJ-E	do	*k*	B	8 by 12 by 12	6	do	do	80
				J	3¾ by 12 by 12	3			
125	12-O-S	4 by 4	*p-1*	O	8 by 6¼ by 12	T-shaped	do	do	80
[6]125a	do	do	*p-1*	O	do	do	do	do	80
126	do	do	*p-1*	O	do	do	Gypsum	Gypsum	80
127	do	8 by 10½	*p-1*	O	do	do	None	None	80
128	do	do	*p-1*	O	do	do	do	do	80
129	do	do	*p-1*	O	do	do	Gypsum	Gypsum	80

(f) 12-INCH WALLS OF FIRE-CLAY TILE

130	12-A-E	4 by 4	*l*	A	8 by 12 by 12	6	None	None	120
131	do	do	*l*	A	do	6	do	do	120
132	do	16 by 11	*l*	A	do	6	do	do	Unrestrained.
133	12-AH-E	4 by 4	*l*	A	do	6	do	do	120
				H	3¾ by 12 by 12	3			
[6]133a	do	do	*l*	A	8 by 12 by 12	6	do	do	120
				H	3¾ by 12 by 12	3			
134	do	do	*l*	A	8 by 12 by 12	6	do	do	120
				H	3¾ by 12 by 12	3			
135	12-G-E	8 by 11	*n*	G	12 by 12 by 12	9	do	do	Restrained.
136	do	do	*n*	G	do	9	Gypsum	Gypsum	Restrained.
137	12-P-S	4 by 4	*l*	P	8 by 10 ¼ by 12	H-shaped	None	None	80
138	do	do	*l*	P	do	do	Gypsum	Gypsum	80
139	12-Q-S	do	*f*	Q	8 by 8 by 8	9	None	None	80
140	do	do	*f*	Q	do	9	Gypsum	Gypsum	80
141	12-VXZ-E	do	*p*	V	8 by 12 by 10½	6	None	Brick	100
				X	8 by 5 by 12	L-shaped			
				Z	2¼ by 3¾ by 8	Brick			
142	do	do	*p*	V	8 by 12 by 10½	6	Gypsum	do	100
				X	8 by 5 by 12	L-shaped			
				Z	2¼ by 3¾ by 8	Brick			

[6] Was dried to nearly constant weight before testing.

TABLE 9.—*Program of fire-endurance tests*—Continued

(*f*) 12-INCH WALLS OF FIRE-CLAY TILE—Continued

Wall			Tile units			Number of cells or special design	Plaster		Restraint or load
No.	Type	Size (feet)	Source	Design	Size (inches)		Exposed side	Unexposed side	
									*Lbs./in.*²
143	12-VXZ-E	4 by 4	*p*	V	8 by 12 by 10½	6	Brick	None	100
				X	8 by 5 by 12	L-shaped			
				Z	2¼ by 3¾ by 8	Brick			
144	do	do	*p*	V	8 by 12 by 10½	6	Gypsum	Brick	100
				X	8 by 5 by 12	L-shaped			
				Z	2¼ by 3¾ by 8	Brick			
145	12-WY-E	do	*p*	W	12 by 12 by 10½	9	do	None	100
				Y	12 by 5 by 12	L-shaped			
146	12-LMZ-S	8 by 10¼	*m*	L	8 by 5 by 12	2	do	Brick	80
				M	3¾ by 5 by 12	1			
				Z	2¼ by 3¾ by 8	Brick			
147	12-VXZ-E	do	*m*	V	8 by 12 by 10½	6	do	do	80
				X	8 by 5 by 12	L-shaped			
				Z	2¼ by 3¾ by 8	Brick			

(*g*) 16-INCH WALL OF SHALE TILE

148	16-AH-E	16 by 11	*d*	A	8 by 12 by 12	6	None	None	Restrained.
				H	3¾ by 12 by 12	3			

(*h*) 16-INCH WALLS OF SURFACE-CLAY TILE

149	16-O-S	4 by 4	*p-1*	O	8 by 6¼ by 12	T-shaped	None	None	80
150	do	do	*p-1*	O	do	do	Gypsum	Gypsum	80

(*i*) 16-INCH WALLS OF FIRE-CLAY TILE

151	16-AH-E	16 by 11	*l*	A	8 by 12 by 12	6	None	None	Restrained.
				H	3¾ by 12 by 12	3			
152	do	do	*l*	A	8 by 12 by 12	6	do	do	Unrestrained.
				H	3¾ by 12 by 12	3			
153	do	4 by 4	*l*	A	8 by 12 by 12	6	do	do	
				H	3¾ by 12 by 12	3			
154	do	do	*l*	A	8 by 12 by 12	6	do	do	

153	do	4 by 4	*l*	H	3¾ by 12 by 12	3	do	do	150
154	do	do	*l*	A	8 by 12 by 12	6	Gypsum	Gypsum	150
				H	3¾ by 12 by 12	3			
155	16-LM-S	8 by 11	*m*	L	8 by 5 by 12	2	None	None	Restrained.
				M	3¾ by 5 by 12	1			
156	16-KM-S	do	*m*	K	8 by 5 by 12	3	do	do	Restrained.
				M	3¾ by 5 by 12	1			
157	do	4 by 4	*m*	K	8 by 5 by 12	3	do	do	80
				M	3¾ by 5 by 12	1			
158	do	do	*m*	K	8 by 5 by 12	3	Gypsum	Gypsum	80
				M	3¾ by 5 by 12	1			
159	16-P-S	16 by 11	*l*	P	8 by 10¼ by 12	H-shaped	None	None	Restrained.
160	do	4 by 4	*l*	P	do	do	do	do	80
[6]160a	do	do	*l*	P	do	do	do	do	80
161	do	do	*l*	P	do	do	Gypsum	Gypsum	80
162	16-Q-S	do	*f*	Q	8 by 8 by 8	9	None	None	100
163	do	do	*f*	Q	do	9	Gypsum	Gypsum	Restrained.
				W	12 by 12 by 10½	9			
164	16-WYZ-E	do	*p*	Y	12 by 5 by 12	L-shaped	do	Brick	100
				Z	2¼ by 3¾ by 8	Brick			

[6] Was dried to nearly constant weight before testing.

TABLE 10.—*Program of fire and water tests*

Wall			Tile units			Number of cells or special design	Plaster		Restraint
No.	Type	Clay	Source	Design	Size (inches)		Exposed side	Unexposed side	
165–1	8–D–E	Fire	*m*	D	8 by 12 by 12	Double-shell	None	None	Unrestrained.
2	8–Q–E	do	*f*	Q	8 by 8 by 8	9			
3	8–K–S	do	*m*	K	8 by 5 by 12	3			
4	8–C–E	Surface	*j*	C	8 by 12 by 12	9			
5	8–A–E	Fire	*l*	A	do	6			
6	do	Shale	*d*	A	do	6			
7	8–P–S	Fire	*l*	P	8 by 10¼ by 12	H-shaped			
8	8–B–E	do	*m*	B	8 by 12 by 12	6			
9	do	Surface	*k*	B	do	6			
10	8–O–S	Shale	*d–1*	O	8 by 6¼ by 12	T-shaped			
11	do	Surface	*p–1*	O	do	do			
12	8–A–E	Fire	*n*	A	8 by 12 by 12	6			
166–1	do	Shale	*d*	A	do	6	None	None	Restrained.
2	8–O–S	Surface	*p–1*	O	8 by 6¼ by 12	T-shaped			
3	8–E–E	Fire	*m*	E	8 by 12 by 5	Double-shell			
4	8–C–E	Surface	*j*	C	8 by 12 by 12	9			
5	8–B–E	Fire	*m*	B	do	6			
6	8–C–E	Surface	*j*	C	do	9			
7	8–A–E	Shale	*d*	A	do	6			
8	8–B–E	Surface	*k*	B	do	6			
9	8–A–E	Fire	*n*	A	do	6			
10	8–P–S	do	*l*	P	8 by 10¼ by 12	H-shaped			
11	8–K–S	do	*m*	K	8 by 5 by 12	3			
12	8–A–E	do	*l*	A	8 by 12 by 12	6			
167–1	8–C–E	Surface	*j*	C	do	9	Gypsum	None	Do.
2	8–Q–E	Fire	*f*	Q	8 by 8 by 8	9			
3	8–K–S	do	*m*	K	8 by 5 by 12	3			
4	8–D–E	do	*m*	D	8 by 12 by 12	Double-shell			
5	8–B–E	Surface	*k*	B	do	6			
6	8–A–E	Shale	*d*	A	do	6			
7	8–P–S	Fire	*l*	P	8 by 10¼ by 12	H-shaped			
8	8–B–E	do	*m*	B	8 by 12 by 12	6			
9	8–A–E	do	*l*	A	do	6			
10	8–O–S	Shale	*d–1*	O	8 by 6¼ by 12	T-shaped			
11	do	Surface	*p–1*	O	do	do			
12	8–A–E	Fire	*n*	A	8 by 12 by 12	6			
168–1	12–BJ–E	Surface	*k*	B	do	6	Cement	None	Unrestrained.
				J	3¾ by 12 by 12	3			
2	12–CH–E	do	*j*	C	8 by 12 by 12	9			
				H	3¾ by 12 by 12	3			
3	12–AH–E	Shale	*d*	A	8 by 12 by 12	6			
				H	3¾ by 12 by 12	3			
4	12–G–E	Fire	*n*	G	12 by 12 by 12	9			
5	do	do	*n*	G	do	9			
6	12–F–E	do	*m*	F	do	6			
7	12–D–E	do	*m*	D	do	Double-shell			
8	12–B–E	Surface	*k*	B	8 by 12 by 12	6			
9	12–D–E	Fire	*m*	D	12 by 12 by 12	Double-shell			
10	12–A–E	Shale	*d*	A	8 by 12 by 12	6			
11	12–C–E	Surface	*j*	C	do	9			
12	12–F–E	Fire	*l*	F	12 by 12 by 12	6			

4. CONSTRUCTION OF TEST WALLS

(a) SIZE

Walls of two sizes were tested, hereinafter referred to as small and large. The small wall was approximately 4 feet wide and 4 feet high, which is the size tested in the small furnace described in Section II of this paper. The full-size large wall, which is the size tested in the large furnace described in this part of the paper, is approximately

feet long and 11 feet high for restrained and unrestrained walls and 16 feet wide and 10⅓ feet high for loaded walls. As the width of the wall, more especially when loaded and free at the edges, is not very important beyond a certain limit, many of the large walls tested under load were divided into two sections or walls, each about 8 feet wide and 10⅓ feet high, so that, in effect, two walls could be tested simultaneously and be subjected to nearly the same fire exposure. No differentiation between walls of the 8 and 16 foot width is made in this paper.

(b) RESTRAINT AND LOADING

The walls were built so that the tests could be made under conditions representative of typical uses in building construction. Some were built within rigid frames giving restraint on all edges, representing panel or curtain wall construction. Others were built with no restraint at either the top or the ends, representative of conditions in the top building story or in one-story buildings. For the 8-inch unrestrained walls 16-inch pilasters were built into each end in an effort to give them approximately the same stability under fire conditions as a section of similar size in a longer wall. Such pilasters were not built for the 12 and 16 inch unrestrained walls. The majority of the walls, however, were built so that the vertical edges did not come in contact with the frames, which were equipped with water-cooled hydraulic jacks for applying definite working loads during the fire exposure.

(c) WORKMANSHIP

Eight different masons were employed in the construction of walls. Two of the masons, A and I, were regularly attached to the bureau personnel and were continuously employed in construction work. The masons B and H were working for contractors who were building the walls for a stipulated sum per wall. The masons C, D, E, F, and G were obtained from a local contractor for short periods on a per diem basis. All of the masons were instructed to build the walls with no more care than they would use on a commercial job. No other instructions with regard to workmanship were given. Examinations of tested walls showed that all of the webs and shells of some of the end-construction tiles were bedded in the horizontal joints, while in others only the exterior shells and a part of the cross webs were bedded. For all of the side-construction walls a full horizontal mortar bed was obtained. Full vertical joints were never obtained in either the end or side construction walls. Instead, a narrow band of mortar was placed near the faces of the end-construction tile or on the ends of the shells of the side-construction tile. In this way it was possible to have air circulation from the cells on one side to those on the other side in both the end and side construction walls, the communication being around the ends of the units.

The construction data for the large walls are given in Table 11; those for the small walls are not given, as they were not large enough to give reliable data. The time required to build each wall was recorded, time being taken out for adjustments of scaffolds, as on construction work the mason is always able to move to other sections and is not delayed by changing of scaffolds. However, the extra time required to level off the top of the wall and wedge it up against the frame was included.

TABLE 11.—*Construction and strength data for large walls*

Wall			Tile units		Mason	Time for building	Rate of building	Weight of mortar	Mortar per square foot	Mortar cube strength at 60 days [1]	Masonry strength	
No.	Type	Size (feet)	Number of cells or type	Size of unit (inches)							Before fire	After fire
						H. m.	*Ft.²/hr.*	*Lbs.*	*Lbs.*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*
8-INCH WALLS OF SHALE TILE												
2	8-A-E	8 by 10⅓	6	8 by 12 by 12	A	4 40	17.7	700	8.5	935	890	
3	do	do	6	do	A	4 40	17.7	676	8.2	[2]1,170	780	
4	do	16 by 10⅓	6	do	D	7 30	22.0	1,655	10.0	780	535	
6	do	16 by 11	6	do	A	9 30	18.5	1,426	8.1	830	560	
8	8-A-S	8 by 10⅓	6	do	E	2 30	33.1	777	9.4	1,150	395	
9	8-A-E	do	6	do	D	5 05	16.3	772	9.3	860	535	
15	8-E-E	do	D. S.	8 by 12 by 5	D	4 50	17.1	772	9.3	860	670	
21	8-O-S	do	T.	8 by 6¼ by 12	A	6 10	13.4	830	10.0	755	350	
25	8-Q-S	do	9	8 by 8 by 8	E	4 05	20.2	1,148	13.9	1,190	360	
8-INCH WALLS OF SURFACE CLAY TILE												
34	8-C-E	8 by 10⅓	9	8 by 12 by 12	A	3 35	23.1	864	10.5	885	515	
35	do	do	9	do	A	3 35	23.1	829	10.0	[2]1,135	670	
36	do	8 by 11	9	do	A	3 45	23.5	745	8.5	600	480	
37	do	do	9	do	A	3 45	23.5	745	8.5	600	480	
38	do	8 by 10⅓	9	do	E	3 30	23.6	930	11.2	950	305	
39	do	do	9	do	E	3 30	23.6	930	11.2	950	305	
42	8-B-E	16 by 11	6	do	B	5 30	32.0	1,564	8.9	460	665	
43	do	8 by 10⅓	6	do	A	3 25	24.2	587	7.1	755	370	
44	do	do	6	do	A	3 25	24.2	664	8.0	[2]1,270	540	
45	do	8 by 11	6	do	A	3 55	22.5	825	9.4	310	455	
46	do	do	6	do	A	3 55	22.5	825	9.4	310	455	
60	8-O-S	8 by 10⅓	T.	8 by 6¼ by 12	A	6 10	13.7	830	10.0	757	255	
8-INCH WALLS OF FIRE CLAY TILE												
67	8-A-E	16 by 11	6	8 by 12 by 12	A	8 45	20.1	1,930	11.0	910	570	
68	do	do	6	do	A	9 0	19.6	1,920	10.9	375	550	
69	do	8 by 10⅓	6	do	A	3 45	22.0	586	7.1	1,320	315	
70	do	do	6	do	A	3 45	22.0	586	7.1	1,320	315	
71	do	8 by 11	6	do	A	4 00	22.0	700	8.0	745	360	
72	do	do	6	do	A	4 00	22.0	700	8.0	745	360	
74	do	8 by 10⅓	6	do	C	3 45	22.0	760	9.2	[3]440	170	
75	do	do	6	do	C	3 45	22.0	780	9.4	295	300	
76	do	16 by 11	6	do	A	8 15	21.3	1,978	11.2	680	665	
77	do	8 by 11	6	do	A	3 25	25.8	820	9.3	550	255	
78	do	do	6	do	A	3 25	25.8	820	9.3	550	255	
79	8-A-S	8 by 10⅓	6	do	A	3 00	27.6	475	5.7	680	340	
80	do	do	6	do	A	3 00	27.6	475	5.7	680	340	
81	do	8 by 11	6	do	A	3 55	22.5	525	6.0	770	355	
82	do	do	6	do	A	3 55	22.5	525	6.0	770	355	
85	8-B-E	do	6	do	A	2 55	30.2	775	8.8	960	315	

[1] Mortar proportion for walls was 1:1:4, Portland cement, hydrated lime, and sand, by loose volume except where otherwise indicated.

[2] Cement mortar.

TABLE 11.—*Construction and strength data for large walls*—Continued

8-INCH WALLS OF FIRE CLAY TILE—Continued

No.	Wall: Type	Wall: Size (feet)	Tile units: Number of cells or type	Tile units: Size of unit (inches)	Mason	Time for building	Rate of building	Weight of mortar	Mortar per square foot	Mortar cube strength at 60 days	Masonry strength: Before fire	Masonry strength: After fire
						H. m.	*Ft.²/hr.*	*Lbs.*	*Lbs.*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*
86	8-B-E	8 by 11	6	8 by 12 by 12	A	2 55	30.2	775	8.8	960	315	385
87	do	do	6	do	E	3 55	32.5	1,152	13.1	1,000	-----	-----
88	8-BI-E	do	6 3	8 by 12 by 12 2 by 12 by 12	E	3 55	32.5	1,152	13.1	1,000	-----	-----
89	8-D-E	do	D. S.	8 by 12 by 12	A	3 25	25.8	550	6.2	770	565	265
90	do	do	D. S.	do	A	3 25	25.8	550	6.2	770	565	385
95	8-K-S	do	3	8 by 5 by 12	A	7 15	12.1	1,045	11.9	980	270	250
96	do	do	3	do	A	6 15	14.1	855	9.7	760	495	230
97	8-L-S	do	2	do	A	7 15	12.1	1,045	11.9	980	240	210
98	do	do	2	do	A	6 15	14.1	855	9.7	760	375	250
105	8-P-S	do	H	8 by 10¼ by 12	A	3 30	25.1	615	7.0	550	-----	275
106	do	do	H	do	A	3 30	25.1	615	7.0	550	-----	340
110	10-H-S	8 by 10⅓	3	3¾ by 12 by 12	A	5 55	14.0	670	8.1	1,065	455	210
111	10-N-S	do	2	3¾ by 5 by 12	A	5 55	14.0	670	8.1	1,065	535	340
112	8-MZ-S	do	1	do	A	11 00	7.5	1,345	16.3	685	970	530
113	8-JZ-E	do	3	3¾ by 12 by 10½	A	11 00	7.5	1,345	16.3	685	1,000	575

12-INCH WALL OF SHALE TILE

118	12-O-S	8 by 10⅓	T	8 by 6¼ by 12	A	-----	-----	-----	-----	-----	-----	150

12-INCH WALLS OF SURFACE CLAY TILE

123	12-CH-E	8 by 10⅓	9 3	8 by 12 by 12 3¾ by 12 by 12	A	6 45	12.2	889	10.8	845	320	-----
124	12-BJ-E	do	6 3	8 by 12 by 12 3¾ by 12 by 12	A	6 45	12.2	794	9.6	910	450	-----
127	12-O-S	do	T	8 by 6¼ by 12	A	7 45	10.7	1,299	15.7	725	300	85
128	do	do	T	do	A	8 00	10.3	1,212	14.7	1,025	330	-----
129	do	do	T	do	A	8 00	10.3	1,212	14.7	1,025	330	120

12-INCH WALLS OF FIRE CLAY TILE

132	12-A-E	16 by 11	6	8 by 12 by 12	A	9 00	19.6	1,914	10.9	655	375	190
135	12-G-E	8 by 11	9	12 by 12 by 12	A	4 55	17.9	1,003	11.4	830	-----	195
136	do	do	9	do	A	4 55	17.9	1,003	11.4	830	-----	235
146	12-LMZ-S	8 by 10⅓	2 1	8 by 5 by 12 3¾ by 5 by 12	A	9 35	8.6	1,542	18.7	750	425	220
147	12-VXZ-E	do	6 L-shaped.	8 by 12 by 10½ 8 by 5 by 12	A	9 35	8.6	1,542	18.7	750	540	360

16-INCH WALL OF SHALE TILE

148	16-AH-E	16 by 11	6 3	8 by 12 by 12 3¾ by 12 by 12	A	12 45	13.8	3,700	21.0	1,280	550	-----

16-INCH WALLS OF FIRE CLAY TILE

151	16-AH-E	16 by 11	6 3	8 by 12 by 12 3¾ by 12 by 12	A	16 45	10.5	3,199	18.2	770	600	180
152	do	do	6 3	8 by 12 by 12 3¾ by 12 by 12	C	12 15	14.4	3,020	17.2	655	335	165
155	16-LM-S	8 by 11	2 1	8 by 5 by 12 3¾ by 5 by 12	A	8 35	10.3	1,992	22.6	810	180	130
156	16-KM-S	do	3 1	8 by 5 by 12 3¾ by 5 by 12	A	8 35	10.3	1,992	22.6	810	295	120
159	16-P-S	16 by 11	H	8 by 10¼ by 12	A	16 30	10.7	2,857	16.2	785	300	-----

TABLE 11.—*Construction and strength data for large walls*—Continued

FIRE AND WATER TESTS

No.	Wall: Type	Wall: Size (feet)	Tile units: Number of cells or type	Tile units: Size of unit (inches)	Mason	Time for building	Rate of building	Weight of mortar	Mortar per square foot	Mortar cube strength at 60 days	Masonry strength: Before fire	Masonry strength: After fire
						H. m.	*Ft.²/hr.*	*Lbs.*	*Lbs.*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*
165–1	8–D–E	16 by 11	D. S.	8 by 12 by 12	A	[3]	[3]	[3]	[3]	[3]	565	245
2	8–Q–E		9	8 by 8 by 8		[3]	[3]	[3]	[3]	[3]	----	515
3	8–K–S		3	8 by 5 by 12		[3]	[3]	[3]	[3]	[3]	380	265
4	8–C–E		9	8 by 12 by 12		[3]	[3]	[3]	[3]	[3]	435	295
5	8–A–E		6	do		[3]	[3]	[3]	[3]	[3]	405	----
6	do		6	do		[3]	[3]	[3]	[3]	[3]	630	350
7	8–P–S		H-shaped.	8 by 10¼ by 12		[3]	[3]	[3]	[3]	[3]	----	----
8	8–B–E		6	8 by 12 by 12		[3]	[3]	[3]	[3]	[3]	315	380
9	do		6	do		[3]	[3]	[3]	[3]	[3]	495	225
10	8–O–S		T-shaped.	8 by 6¼ by 12		[3]	[3]	[3]	[3]	[3]	350	175
11	do		do	do		[3]	[3]	[3]	[3]	[3]	255	195
12	8–A–E		6	8 by 12 by 12		[3]	[3]	[3]	[3]	[3]	450	305
166–1	do	16 by 11	6	do	A	[3]	[3]	[3]	[3]	[3]	630	275
2	8–O–S		T-shaped.	8 by 6¼ by 12		[3]	[3]	[3]	[3]	[3]	255	350
3	8–E–E		D. S.	8 by 5 by 12		[3]	[3]	[3]	[3]	[3]	----	540
4	8–C–E		9	8 by 12 by 12		[3]	[3]	[3]	[3]	[3]	435	175
5	8–B–E		6	do		[3]	[3]	[3]	[3]	[3]	315	260
6	8–C–E		9	do		[3]	[3]	[3]	[3]	[3]	435	205
7	8–A–E		6	do		[3]	[3]	[3]	[3]	[3]	630	275
8	8–B–E		6	do		[3]	[3]	[3]	[3]	[3]	495	295
9	8–A–E		6	do		[3]	[3]	[3]	[3]	[3]	450	355
10	8–P–S		H-shaped.	8 by 10¼ by 12		[3]	[3]	[3]	[3]	[3]	----	215
11	8–K–S		3	8 by 5 by 12		[3]	[3]	[3]	[3]	[3]	380	235
12	8–A–E		6	8 by 12 by 12		[3]	[3]	[3]	[3]	[3]	405	250
167–1	8–C–E	16 by 11	9	do	A	[3]	[3]	[3]	[3]	[3]	435	205
2	8–Q–E		9	8 by 8 by 8		[3]	[3]	[3]	[3]	[3]	----	575
3	8–K–S		3	8 by 5 by 12		[3]	[3]	[3]	[3]	[3]	380	305
4	8–D–E		D. S.	8 by 12 by 12		[3]	[3]	[3]	[3]	[3]	565	375
5	8–B–E		6	do		[3]	[3]	[3]	[3]	[3]	495	365
6	8–A–E		6	do		[3]	[3]	[3]	[3]	[3]	630	660
7	8–P–S		H-shaped.	8 by 10¼ by 12		[3]	[3]	[3]	[3]	[3]	----	205
8	8–B–E		6	8 by 12 by 12		[3]	[3]	[3]	[3]	[3]	315	690
9	8–A–E		6	do		[3]	[3]	[3]	[3]	[3]	405	325
10	8–O–S		T-shaped.	8 by 6¼ by 12		[3]	[3]	[3]	[3]	[3]	350	235
11	do		do	do		[3]	[3]	[3]	[3]	[3]	255	200
12	8–A–E		6	8 by 12 by 12		[3]	[3]	[3]	[3]	[3]	450	420
168–1	12–BJ–E	16 by 11	6 3	do 3¾ by 12 by 12	A	[3]	[3]	[3]	[3]	[3]	450	235
2	12–CH–E		9 3	8 by 12 by 12 3¾ by 12 by 12		[3]	[3]	[3]	[3]	[3]	320	95
3	12–AH–E		6 3	8 by 12 by 12 3¾ by 12 by 12		[3]	[3]	[3]	[3]	[3]	----	260
4	12–G–E		9	12 by 12 by 12		[3]	[3]	[3]	[3]	[3]	----	215
5	do		9	do		[3]	[3]	[3]	[3]	[3]	----	315
6	12–F–E		6	do		[3]	[3]	[3]	[3]	[3]	----	170
7	12–D–E		D. S.	do		[3]	[3]	[3]	[3]	[3]	----	145
8	12–B–E		6	8 by 12 by 12		[3]	[3]	[3]	[3]	[3]	----	360
9	12–D–E		D. S.	12 by 12 by 12		[3]	[3]	[3]	[3]	[3]	----	340
10	12–A–E		6	8 by 12 by 12		[3]	[3]	[3]	[3]	[3]	----	485
11	12–C–E		9	do		[3]	[3]	[3]	[3]	[3]	----	255
12	12–F–E		6	12 by 12 by 12		[3]	[3]	[3]	[3]	[3]	----	260

[3] Because of the small size of the sections, reliable data were not obtained.

The rate of building the walls depends upon the workability of the mortar used, the skill of the mason, and the construction, design, and quality of the tiles used. Since for most of the walls one kind of mortar was used, no definite information was obtained on the effect of mortar proportions on the rate of laying the tile. The fact that the rate of laying the tile is governed by the ability of the mason is shown in the time required to lay walls 86 and 87, which were alike in all respects. As built by different masons, one required 35 per cent longer time than the other.

While an effort was made to have conditions, other than the design of the wall construction and mortar proportion, the same throughout, this can not be premised. The work of the mason was affected by the skill of the helpers, as well as by different degrees of efficiency of a given mason on different days. Hence, any difference in time required to lay up walls of the various units should not be attributed wholly to the size and shape of the tile units employed.

(d) MORTAR

A cement-lime mortar of 1:1:4 volume proportions of Portland cement, lime, and sand, respectively, was used for laying up most of the walls. In order to determine whether the mortar affects the fire resistance, a few of the walls were built with a cement mortar of 1:3 cement and sand volume proportions with lime added equal to 10 per cent of the volume of the cement.

Although the mortar was considered as proportioned by volume, equivalent proportions by weight were actually used. The weights were based on the assumption that a cubic foot of hydrated lime weighs 40 pounds, a cubic foot of Portland cement (one bag) weighs 94 pounds, and that the dried contents of a cubic foot of damp sand weigh 80 pounds. Since it was necessary to use damp sand of variable moisture content, the moisture content of a sample of sand was determined before starting the construction of each wall, and the weight of damp sand required for the necessary weight of dry sand was computed. In this way fairly constant proportions of dry materials were used, but the mason's helper was allowed to add enough water to give the consistency desired by the mason. Three or more mortar cubes for compression tests were made at the time of mixing each batch of mortar.

The decision to use the 1:1:4 cement-lime mortar was made after consulting with contractors and masons as to the mixture they had found most economical and workable. It developed that where the mortar specification was not definite or was left to the mason or masonry contractor fairly rich cement-lime mortars were used on account of superior workability and consequent better rate of tile laying. While workability is also a function of the gradation of the

sand, for the sand used in these tests the 1:1:4 mortar proportion was no richer than necessary if proper workmanship was to be obtained.

(1) MORTAR MATERIALS.—Portland cement was obtained on Government contract in 10 to 20 barrel lots. Samples of the cement were tested and found to comply with Federal specifications for this material. The chemical analysis and results of acceptance tests of four samples are given in Table 12.

The lime used was mason's hydrate obtained on Government contract in small lots to assure fresh material.

Potomac River building sand was used for all mortar and plaster. This is a siliceous sand of uniform gradation and low silt content:

TABLE 12.—*Analyses of Portland cement*

Sample No.	1	2	3	4	Average
Chemical analysis:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Silica (SiO_2)			22.20	22.20	22.20
Oxide of iron (Fe_2O_3)			2.58	2.51	2.54
Oxide of aluminum (Al_2O_3)			6.54	6.01	6.28
Lime (CaO)			60.40	60.16	60.28
Magnesia (MgO)	3.35	3.67	3.89	4.11	3.76
Sulphuric anhydride (SO_3)	1.77	1.77	1.70	1.78	1.76
Loss on ignition	2.63	2.27	1.43	1.86	2.05
Insoluble residue	.40	.32	.29	.36	.34
Fineness passing 200-mesh sieve	83.8	81.6	79.8	81.0	81.5
Tensile strength, 1 cement: 3 Ottawa sand:	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*
7 days	267	282	234	270	263
28 days	365	357	372	377	368
Time of set:	*Hr. min.*	*Hr. min.*	*Hr. min.*	*Hr. min.*	*Hr. min.*
Initial	3 40	3 10	4 10	3 30	3 30
Final	6 50	5 30	7 05	6 10	6 32
Soundness pats, 5 hours in steam	o. k.	o. k.	o. k.	o. k.	
Water used:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Neat	22.5	22.0	22.0	22.0	22.1
1:3 mortar	10.2	10.2		10.2	10.2

The gypsum plaster was obtained on Government contract in l to 3 ton lots. The time of set of all samples was determined. It was difficult at times to obtain material that would set before drying out. The complete analysis of one sample is given in Table 13.

TABLE 13.—*Analysis of sisal fibered gypsum plaster*

Chemical analysis:		
Calcium oxide (CaO)	per cent	30.20
Sulphur trioxide (SO_3)	do	44.70
Combined water (H_2O)	do	4.24
Calcined gypsum content, ($CaSO_4 \cdot \frac{1}{2}H_2O$) calculated from combined water	do	68.30
Fiber	do	.39
Time of set	hours	24
Tensile strength	lbs./in.²	207

5. STORING AND AGING OF WALLS

The walls were not moved after they were built until the mortar had set. They were then stored as is shown in Figures 8 and 14 (pp. 33 and 69). The large walls were built in a structure located on low ground where the humidity was usually high. During the

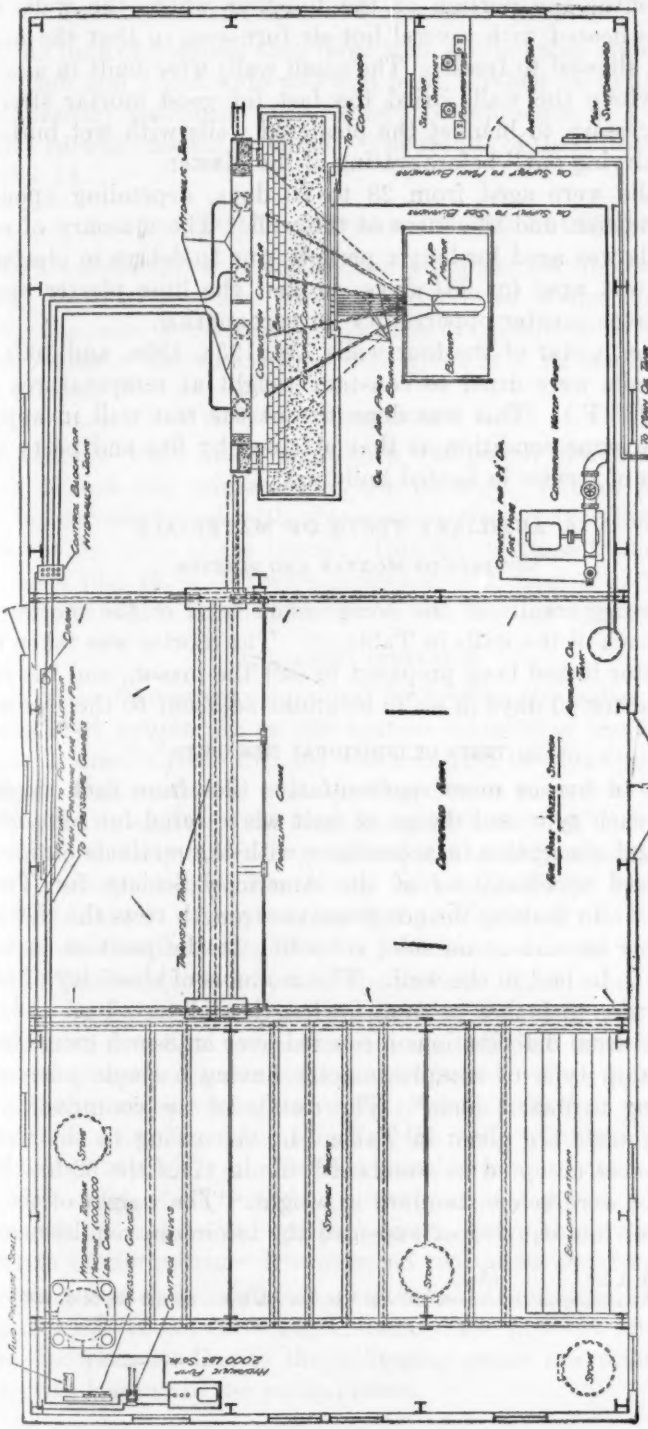


FIG. 14.—*Plan layout of large furnace and related equipment*

winter months the portion of the building where the walls were stored was heated with several hot-air furnaces, so that the mortar was never allowed to freeze. The small walls were built in a heated building where the walls dried too fast for good mortar strength. It was necessary to blanket the plastered walls with wet burlap to prevent "drying out" before setting of the plaster.

The walls were aged from 28 to 70 days, depending upon the drying condition and thickness of the wall. The masonry of a few of the walls was aged for longer periods, due to delays in plastering. One wall was aged for 384 days, so that the lime plaster applied could be given greater opportunity for carbonating.

After the mortar of the four walls 73a, 125a, 133a, and 160a had set, the walls were dried to constant weight at temperatures near 50° C. (122° F.). This was done to put the test wall in approximately the same condition as that attained by fire and party walls after years of service in heated buildings.

6. AUXILIARY TESTS OF MATERIALS

(a) TESTS OF MORTAR AND PLASTER

The average results of the compression tests of the mortars are given for each of the walls in Table 11. The mortar was taken from the mix after it had been prepared to suit the mason, and the cubes were stored for 60 days in air in locations adjacent to the test walls.

(b) TESTS OF INDIVIDUAL TILE UNITS

Samples of five or more representative tiles from each shipment and from each type and design of unit were tested for compressive strength and absorption in accordance with the methods outlined in the standard specifications of the American Society for Testing Materials.[20] In making the compressive-strength tests the tiles were tested either on end or on side, according to the position in which they were to be laid in the wall. The modulus of elasticity of representative tile, 10 inches or more in length and tested on end, was determined from deformations measured over an 8-inch gauge length with a clamp type of compressometer having a single micrometer dial reading to 0.0001 inch.[21] The results of the compression and absorption tests are given in Table 14. According to the weights and tolerances accepted as standard,[20] tile in 17 of the 62 lots listed in Table 14 were below standard in weight. The weight of the tiles in the other lots equaled or exceeded the minimum requirements.

[20] Appendix B, p. 326.

[21] "Capping for compression specimens," Jr. Am. Cer. Soc., **6**, No. 5, pp. 623–629; May, 1923.

(c) COMPRESSIVE STRENGTH OF MASONRY SPECIMENS

At the time of building each large wall, a small wall approximately 3 feet high and 3 feet wide was also built. When 28 to 35 days old these masonry specimens were tested in compression in a 1,000,000-pound hydraulic testing machine. The results of these tests are given in Table 11.

7. DESCRIPTION OF FURNACE AND EQUIPMENT

Two separate furnaces and sets of equipment were used in conducting these tests. The furnace and related equipment used in making the tests of the 4 by 4 foot walls are described in Section III of this paper. The description here given will be confined to the large furnace.

(a) FRAMES FOR CONTAINING WALLS

The frames were made of 20-inch 140-pound Bethlehem girder beams riveted and reinforced at the corners. Two of the frames were further reinforced with plates or vertical connecting members riveted to the webs of the beams. One side of these frames and the inner edge (fig. 15, p. 74) were protected with from 4 to 6 inches of concrete, for which crushed fire brick was used as aggregate.

(b) LOADING APPARATUS

Two of the frames were equipped for loading the walls. This was accomplished by placing on the bottom member of the frame four 200-ton hydraulic jacks (fig. 15) which carried two loading beams on which the wall was built. The loading beams were made of a plate and two heavy angles in the form of an inverted "U." Two beams, each approximately 8 feet long, placed end to end, were used so that a more uniform distribution of the load for walls 16 feet in width could be obtained. Also, this made it possible to divide the full-size wall into two walls, each about 8 feet wide, and test them simultaneously with independent load application.

The hydraulic jacks were set in a tank so that they could be water cooled, the 4 inches of concrete not being sufficient protection.

The oil pressure in the jacks was obtained with a triple-plunger pump having an operating valve, by means of which it was possible to maintain a nearly constant load on the wall. The pump was connected (fig. 14) with a multiple-valve block connected with each jack and arranged so that the pressure on any one or more of the jacks could be maintained constant or released without changing the operation of the others. However, no two jacks could be operated simultaneously under different pressures. Three pipe lines led to the pump side of the valve block, namely, the pressure line from the pump, the pressure line to the indicating gauge and scale, and the release line leading to the pump cistern.

TABLE 14.—*Compressive strength and absorption of hollow tile and brick in main series of fire tests*

Source	Fire test wall No.	Clay	Design of unit	Nominal size (inches)	Number of tests	Average weight	Absorption		Position in test	Average area under load		Compressive strength				Average modulus of elasticity (net area)
							Range	Average		Gross	Net	Gross area		Net area		
												Range	Average	Range	Average	
						Pounds	*Per cent*	*Per cent*		*Sq. in.*	*Sq. in.*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Million Lbs./in.²*
a	26, 27	Shale	R	8 by 8 by 12	5	25.6	9.1–14.0	11.5	Side	97.3	26.9	1,116–1,749	1,473	4,033– 6,240	5,330	
c	17	do	K	8 by 5 by 12	5	16.0	9.0–14.4	10.5	do	99.5	26.3	840–1,020	910	3,180– 3,940	3,480	
c–1	22, 23	do	P	8 by 10¼ by 12	5	30.7	10.5–15.4	12.7	do	95.7	27.4	410– 860	640	1,430– 2,980	2,240	
d	1, 114–117	do	A	8 by 12 by 12	5	35.5	6.4–10.9	8.5	End	92.0	38.2	1,970–3,450	2,830	4,700– 8,230	6,820	4.830
d	2–6, 9, 10, 148, 13, 14.	do	A	do	5	38.6	5.6– 7.8	6.7	do	94.1	41.4	2,530–3,610	2,840	5,840– 8,260	6,470	5.750
d	8	do	A	do	5		4.6–10.4	6.4	Side	91.8	22.6	1,370–2,110	1,740	5,480– 8,510	7,080	4.330
d	11, 12	do	A	do	5	36.6	5.8– 7.5	6.9	End	93.1	38.2	2,730–3,520	3,150	6,740– 8,610	7,685	
d	116	do	H	3¾ by 12 by 12	5	19.8	6.4– 7.5	7.0	do	45.5	21.2	4,720–5,640	5,300	10,180–12,200	11,350	
d	15, 16	do	E	8 by 12 by 5	4	16.0	1.2– 8.3	5.3	do	86.9	43.1	4,460–5,790	4,950	9,070–11,770	9,990	
d	24, 25	do	Q	8 by 8 by 8	5	17.2	6.5–11.8	9.4	Side	60.3	15.7	770–1,360	1,010	2,920– 5,320	3,890	
d–1	19, 20	do	O	8 by 6¼ by 12	10	15.1	6.8–15.3	11.4	do	93.3	23.3	840–1,530	1,260	3,240– 6,200	4,950	
d–1	21, 118	do	O	do	10	16.0	11.5–14.2	12.8	do	99.3		610– 930	720	2,300– 3,200	2,740	
d–2	18	do	L	8 by 5 by 12	10	17.0	10.4–13.0	11.7	do	93.6	23.7	710–1,500	1,100	2,770– 5,910	4,340	
d–3	28, 29	do	T	8 by 3½ by 12	5	15.4	3.2– 3.6	3.4	do	94.6		2,280–2,970	2,580			
d–3	30, 31	do	S	8 by 5 by 12	5	18.2	3.0– 3.3	3.1	do	94.4		1,540–2,320	1,950			
f	107, 108, 139, 140, 162, 163.	Fire	Q	8 by 8 by 8	5	17.5	8.7– 9.9	9.0	do	64.5	16.4	650– 880	780	2,630– 3,470	3,070	
f	109	do	Q	do	5	17.3	7.8– 8.6	8.2	End	61.2	27.9	3,270–4,400	3,760	7,070– 9,690	8,250	
h	94	do	K	8 by 5 by 12	10	16.1	16.4–22.0	17.6	Side	99.5	28.9	580–1,030	740	1,910– 3,230	2,520	
j	34–39, 120, 123	Surface	C	8 by 12 by 12	5	35.0	16.7–27.9	22.2	End	89.5	47.9	900–1,630	1,380	1,680– 3,120	2,480	
j	32, 33	do	A	do	5	40.9	16.2–20.9	19.0	do	98.3	52.5	1,300–1,670	1,470	2,350– 3,180	2,760	1.830
j	119, 121, 122	do	C	do	5	34.5	16.8–24.4	21.4	do	89.4	46.6	580–1,440	1,050	1,100– 2,740	2,020	
j	121, 122	do	H	3¾ by 12 by 12	5	18.5	23.6–25.4	24.8	do	47.6	25.2	1,110–1,990	1,650	2,320– 3,720	3,100	
j	120, 123	do	H	do	5	18.1	10.1–23.2	18.0	do	45.1	23.5	810–1,560	1,150	1,530– 3,090	2,230	
k	42–46, 124	do	B	8 by 12 by 12	5	35.8	9.2–13.0	11.5	do	90.6	44.6	1,610–2,790	2,100	3,370– 5,680	4,260	4.540
k	47–59	do	B	do	5	33.6	7.8–19.2	15.1	do	91.9	43.5	1,370–2,040	1,510	3,030– 4,340	3,210	3.590
k	124	do	J	3¾ by 12 by 12	5	21.9	12.6–17.6	15.8	do			1,860–2,960	2,200	2,990– 4,640	3,690	
k–1	62	do	L	8 by 5 by 12	10	15.0	10.4–18.2	15.3	Side	93.6	25.2	670–1,350	1,000	2,460– 4,980	3,710	
k–2	64	do	U	8 by 6 by 12	10	19.9	18.1–23.0	20.3	do	92.8	32.8	350– 580	440	1,010– 1,670	1,240	
k–3	63	do	L	8 by 5 by 12	10	14.1	12.6–14.9	14.1	do	97.1	19.9	700–1,140	950	3,610– 5,500	4,610	
l	73, 130, 131, 133, 134.	Fire	A	8 by 12 by 12	5	34.7	10.8–15.0	11.9	End	98.3	41.0	1,590–3,010	2,550	3,830– 7,130	6,120	
l	74–78, 132, 151–154.	do	A	do	5	35.2	8.9–13.4	11.5	do							
l	79, 82	do	A	do					do							

k-2	63	---do----	L	8 by 5 by 12----	10	14.1	12.6–14.9	14.1	---do----	98.3	41.0	1,390–3,010	1,390	2,780– 5,810	4,170	5,560
k-3	63	---do----	L	8 by 5 by 12----	5	34.7	10.8–15.0	11.9	End----							
k	73, 130, 131, 133, 134.	Fire----	A	8 by 12 by 12----												

l	74–78, 132, 151–154.	---do----	A	---do----	5	35.2	8.9–13.4	11.5	---do----	98.3	40.1	1,060–2,510	1,830	2,560– 6,040	4,470	2.889
l	79, 82	---do----	A	---do----	4	35.2	12.8–13.7	13.2	Side----	97.4	22.1	440– 540	500	1,990– 2,390	2,210	
l	133, 134	---do----	H	3¾ by 12 by 12----	5	18.2	8.2–11.0	9.4	End----	46.7	20.8	3,310–4,570	4,060	7,450–10,610	9,200	
l	151, 152	---do----	H	---do----	5	19.4	9.3–13.0	11.2	---do----	48.9	22.9	1,370–2,100	1,740	2,960– 4,520	3,720	
l	153, 154	---do----	H	---do----	5	17.0	8.8–10.5	9.4	---do----	48.5	19.4	1,770–2,530	2,130	4,440– 6,450	5,330	
l	110	---do----	H	---do----	5	17.2	9.6–10.4	10.2	Side----	48.4	10.9	680–1,310	1,040	3,080– 5,790	4,660	
l	103, 104	---do----	P	8 by 10½ by 12----	10	32.6	8.9–12.4	10.5	---do----	95.8	27.1	990–1,740	1,440	3,540– 6,270	5,110	
l	105, 106, 137, 138, 159–161.	---do----	P	---do----	5	34.8	10.1–14.3	12.6	---do----	99.5	30.8	730–1,390	1,040	2,350– 4,550	3,350	2.210
l	111	---do----	N	3¾ by 5 by 12----	5	8.6	9.4–11.8	10.7	---do----	45.5	11.7	740–1,030	860	2,740– 4,410	3,360	
l-1	101, 102	---do----	O	8 by 6¼ by 12----	10	17.8	4.1–10.2	6.4	---do----	98.7	26.1	860–1,580	1,160	3,380– 5,680	4,410	
l-2	99	---do----	K	8 by 5 by 12----	9	18.7	14.4–16.2	15.2	---do----	97.7	31.4	560– 690	630	1,760– 2,160	1,960	
m	83, 84	---do----	B	8 by 12 by 12----	5		7.6–11.0	8.6	End----	99.1	39.7	2,450–2,980	2,680	6,110– 7,420	6,690	2.430
m	85–88	---do----	B	---do----	5	30.5	5.8–12.8	8.5	---do----			1,140–2,660	2,030	2,840– 6,960	5,280	3.920
m	89, 90	---do----	D	---do----	5	39.1	4.9–10.4	6.9	---do----	96.2	42.0	2,720–3,220	3,060	6,100– 7,470	7,020	
m	91–93	---do----	E	8 by 12 by 5----	5	17.2		8.8	---do----	93.8	37.5	1,670–3,400	2,820	4,190– 8,780	7,240	
m	95, 96, 156–158	---do----	K	8 by 5 by 12----	5	14.4			Side----	94.4	24.0	690–1,020	900	2,710– 4,040	3,540	
m	97, 98, 146, 155	---do----	L	---do----	5	14.4			---do----	92.9	20.2	560– 980	820	2,580– 4,530	3,740	
m	146, 155–158, 112	---do----	M	3¾ by 5 by 12----	5	9.0	5.4–10.0	8.1	---do----	46.3	14.8	1,030–1,330	1,190	3,190– 4,370	3,720	
m	147	---do----	V	8 by 12 by 10½----	5	28.0	4.4– 8.1	6.5	End----	92.2	35.3	2,110–3,330	2,840	5,490– 8,740	7,430	
m	147	---do----	X	8 by 5 by 12----	10	15.3	5.4–10.1	6.5	Side----	92.9		1,620–2,520	1,850			
m	113	---do----	J	3¾ by 12 by 10½----	5	16.9	7.7– 9.4	8.4	End----	47.0	21.8	2,170–2,540	2,320	4,710– 5,460	5,000	
n	67–72	---do----	A	8 by 12 by 12----	5	36.2	15.1–18.3	16.9	---do----	99.5	46.3	1,020–1,500	1,270	2,140– 3,170	2,740	2.140
n	135, 136	---do----	G	12 by 12 by 12----	5	51.2	11.6–20.4	16.8	---do----	143.9	66.0	970–1,400	1,190	2,070– 3,100	2,600	1.980
o-1	61	Surface----	K	8 by 5 by 12----	10	14.9	23.0–24.6	23.8	Side----	95.1	31.4	600–1,060	790	1,820– 3,180	2,400	
p	141–144	Fire----	V	8 by 12 by 10½----	5	37.4	13.7–14.6	14.3	End----	97.5	53.6	1,610–1,990	1,790	2,880– 3,690	3,260	
p	141–144	---do----	X	8 by 5 by 12----	5	17.4	13.8–21.8	17.4	Side----	96.0		660–1,040	760			
p	145, 164	---do----	W	12 by 12 by 10½----	5	53.8	10.4–15.0	12.7	End----	146.1	75.6	3,680–3,990	3,880	1,910– 2,070	2,010	
p	145, 164	---do----	Y	12 by 5 by 12----	5	25.7	9.6–18.8	12.6	Side----	145.8		500– 980	740			
p-1	60, 125–129, 149, 150.	Surface----	O	8 by 6¼ by 12----	5	15.8	13.2–15.0	14.4	---do----	93.3	28.0	290– 400	340	930– 1,310	1,150	
r	40, 41	---do----	A	8 by 12 by 12----	5	33.8	15.0–17.6	16.2	End----	100.9	41.6	1,810–2,240	1,900	4,370– 5,360	4,870	
r	65, 66	---do----	O	8 by 6¼ by 12----	10	14.7	7.4– 9.7	8.6	Side----	91.0	22.3	540– 930	690	2,110– 3,800	2,820	
Face brick.	112, 113, 146, 147		Z	2¼ by 3¾ by 8----	10		12.3–15.0	13.6	Flat----	30.5	30.5	4,330–6,860	5,690	4,330– 6,860	5,690	

The capacity of the loading apparatus was limited by the strength of the frames to a maximum of 400,000 pounds for one frame and 340,000 pounds for the other, which is equivalent to approximately 260 and 225 lbs./in.^{2}, load applied on 8-inch walls. The jacks were calibrated with reference to the readings of the gauges and fluid pressure scale by means of a standard comparison bar with known load-deformation relation.

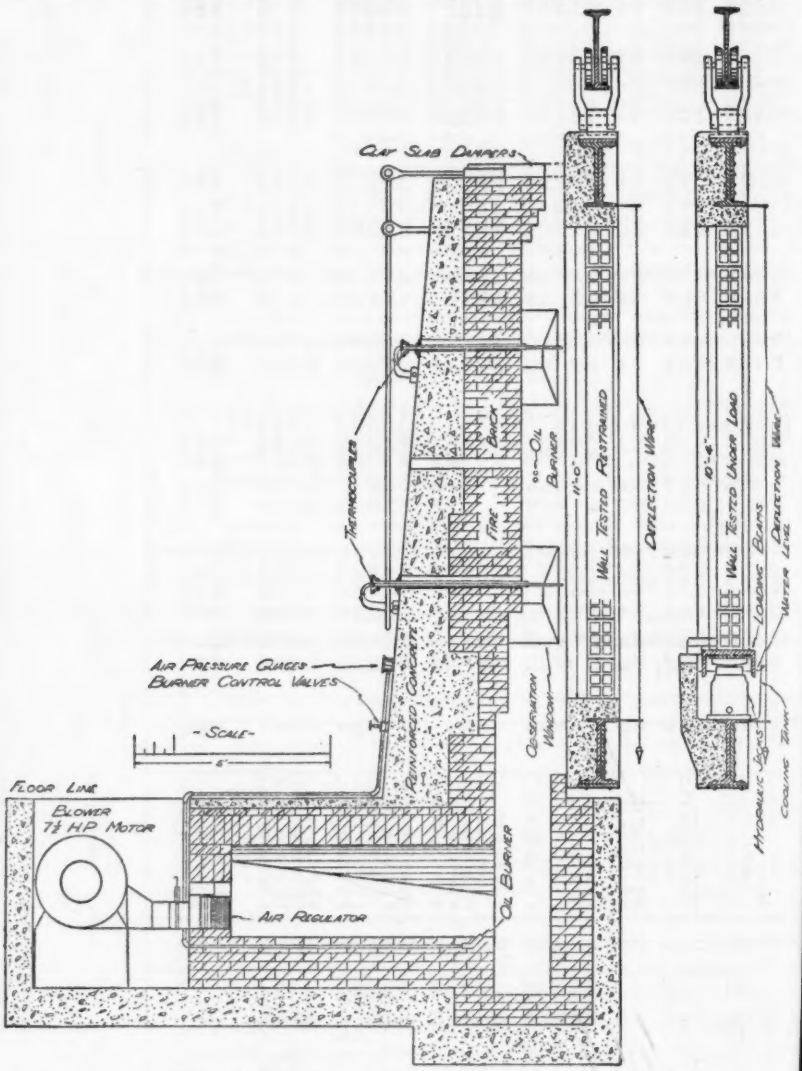


FIG. 15.—*Section through large testing furnace*

(c) APPARATUS FOR MOVING WALLS

Each wall frame was suspended from two trolleys operating on overhead I-beam tracks. A hand-operated traveling crane was available for shifting the frames from the storage tracks to the track

in front of the furnace. A winch was used for pulling the walls along the tracks.

(d) TESTING FURNACE

(1) COMBUSTION CHAMBER.—The combustion chamber is about 1½ feet deep, with the width the same as the wall. The chamber (fig. 15) extends about 8 feet below the bottom of the wall into a pit near the bottom of which the principal burners are placed. The back of the combustion chamber is lined with 9 to 18 inches of fire brick tied into a reinforced-concrete backing. The ends are formed of 18-inch fire-brick walls bonded into the fire brick of the back lining. The top is closed with 4-inch clay slabs, half of which are operated as dampers. The pit and arch over the burners and air duct are lined with fire brick. The air duct tapers from a few feet in width at the back of the furnace to the full width of the pit at the furnace. A sheet-steel hood opening into a stack is mounted over the top of the furnace and serves to carry off most of the smoke and gases of combustion. Two mica-glazed observation holes, placed at two levels in each end, afford means for viewing the exposed side of the wall under test.

(2) BURNERS.—The fire exposure was produced mainly by four oil burners in the pit, distributed as shown in Figure 15. Compressed air at 20 to 25 lbs./in.^{2} pressure was used to atomize the oil at the burners, the pipes through which the air and oil were conducted to the burners being placed under the floor of the air duct. Two auxiliary burners were placed in each end wall of the furnace, one near the mid height and the other 3 feet higher.

A heavy fuel oil of specific gravity from 0.87 to 0.93 was used. The oil-storage tank was placed outside the building and elevated so that the oil was fed to the main burners by gravity under a head of about 12 feet. For the auxiliary burners a supply was provided in a small tank, from which it was forced to the burners by air pressure.

The four main burners were set so that they threw a sheet of flame upward at an angle of approximately 45°. A centrifugal blower, located in a pit at the back of the furnace supplied the additional air needed for proper combustion and for carrying the heat and flame upward and over the exposed side of the wall. The auxiliary burners cover the top corners of the walls, as these portions could not be reached by the flame from the main burners. The air and oil flow to each burner are controlled by valves in the supply lines.

(e) FIRE-STREAM APPARATUS

The water for the fire and water tests was applied through a 2½-inch rubber-lined hose to a national standard play pipe with 1⅛-inch diameter of nozzle. The pressure head was obtained by means of a motor-driven centrifugal pump. A throttling valve was placed in the supply line from the pump, and the pressure gauge was connected with the base of the nozzle.

8. TEMPERATURE MEASUREMENTS

Nearly all temperature measurements were made by the thermoelectric method, alumel-chromel wires being used for the thermocouples placed in the furnace and in the walls, and iron-constantan for those on the unexposed side of the walls. In some of the tests partial-immersion thermometers were used to measure the temperatures under the small pads. The electromotive force of the couples was measured with portable potentiometers, and the corresponding temperature was obtained from comparison calibrations of the wire with standard thermocouples.

(a) INSTRUMENTS

Two dial switches and two portable indicating potentiometers[22] were used in taking the temperature readings. Wires of the same metal as in the thermocouples were used as leads to the switches and to the iced junction.

(b) FURNACE TEMPERATURES

The furnace temperatures were measured with six thermocouples arranged three at each of two levels, the upper couples being 2 feet 8 inches from the top and the lower ones approximately the same distance from the bottom of the wall. The end couples were 2 feet 6 inches from the ends of the wall (see fig. 18). The couples were inserted through the back of the furnace and extended to within about 3 inches from the face of the wall. They were protected by closed-end porcelain tubes, ¾-inch outside diameter and of ⅛-inch wall thickness, or by ½-inch standard iron pipes closed with iron caps. The iron pipes were used to reduce the expense due to breakage of the porcelain tubes. Comparative temperature measurements made during two tests with two thermocouples placed in close proximity, and protected one each by the two respective types of tubes, showed little difference in indicated temperatures (fig. 16).

(c) WALL TEMPERATURES

The wall temperatures at various distances from the exposed side were measured with symmetrically arranged thermocouples placed in the cells of the tile, the leads being insulated with asbestos sleeving. The junctions were placed during the construction of the wall in the cells to a depth of 6 inches or more, the leads being placed parallel to the face of the wall until opposite the joint through which they were taken to the unexposed side. The temperatures on the unexposed side were measured in the earlier tests with unprotected couples fastened to the unexposed surface of the wall with a minimum amount of plaster of Paris placed over about 2 inches of the leads, but not over the junction. In addition, temperatures on the large walls

[22] For description of these potentiometers and theory of operation, see B. S. Tech. Paper No. 170, Pyrometric Practice, p. 52.

were measured under loose cotton contained in an open box 3 feet square and 4 inches deep, placed with the open side against the unexposed side of the wall, and also under a closed box of similar size filled with excelsior. This was done to represent conditions obtained where

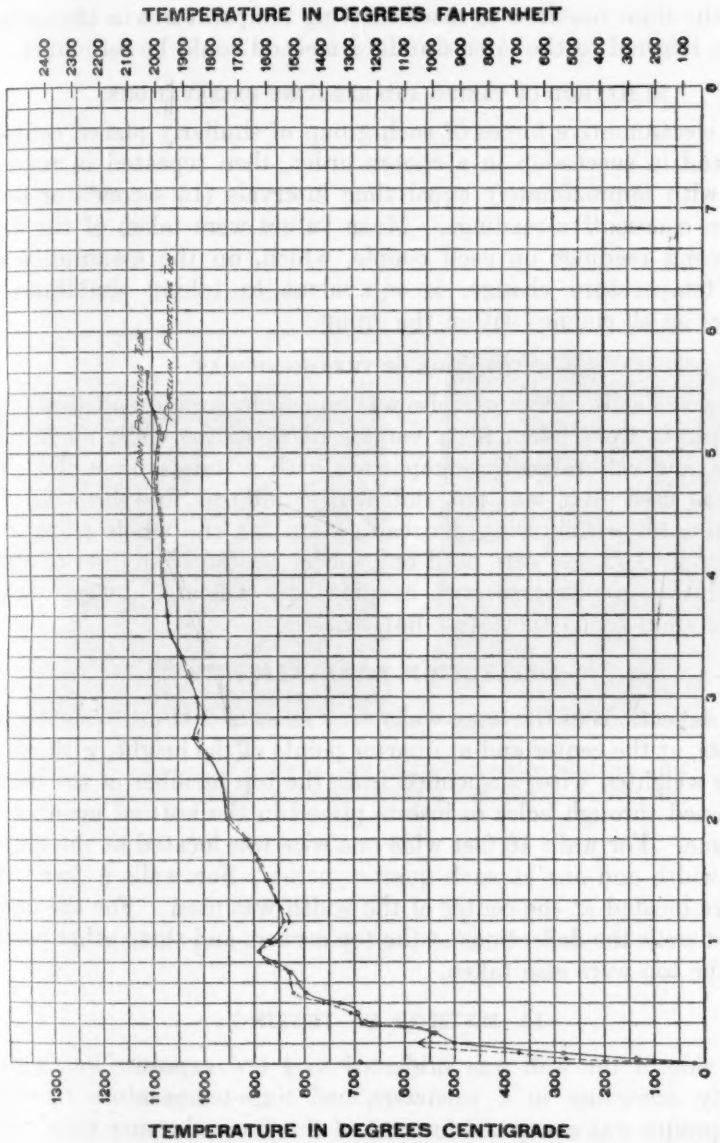


FIG. 16.—*Comparison of temperatures measured near the same point with thermocouples protected by the standard porcelain tube and by iron tube with closed end*

clothing, baled, or crated material is placed against fire or party walls. A cotton and an excelsior box after ignition is shown in Figure 17.

After some of the fire tests had been completed, the specified method of measuring the temperatures on the unexposed surface was standard-

ized to require measurement under oven-dry asbestos fire felt pads 6 inches square and 0.40 inch thick.[23] These pads were applied in all of the later tests. Unprotected couples were also used parallel with them, so that comparative measurements were obtained from which the time required to reach limiting temperatures in the earlier tests as referred to the later standard method could be estimated.

(d) METHOD OF TAKING AND REDUCING OBSERVATIONS

The electromotive forces of each group of similarly placed couples were read in succession in a chosen order, then repeated in reverse order, with approximately equal time intervals (15 seconds or less) between consecutive readings. Mean values were taken of the first and second readings on each couple, which, on the assumption of linear temperature change, is equivalent to taking simultaneous readings on all couples within the group.

(e) CALIBRATION OF THERMOCOUPLES

The wire for the thermocouples was bought in large quantities, from which pieces were taken from various parts of the coils, made into couples, and calibrated by comparison with a standard couple. No wire was used that was not sufficiently uniform in thermoelectric properties to permit using one calibration for the whole shipment. The furnace couples were used only once, except after tests of very short duration. In case wall couples had indicated temperatures above certain limits they were not reused.

9. DEFLECTION MEASUREMENTS

The deflections of the large walls were measured at intervals during the tests, at the center and at quarter points of the height, with reference to weighted wires suspended from the top member of the frame and passed through holes in inserts placed in the bottom member of the frame. For walls 16 feet wide one wire was located at the center of the width and one at each quarter point. For walls 8 feet wide one wire located at the center of the width was used. For the unrestrained walls the deflections at the top corners and three other points along the top were also taken.

10. METHOD OF TESTING

One side of the wall was subjected to a fire exposure varying in intensity according to a predetermined time-temperature relation. The exposure was continued in most of the fire-endurance tests until the limit of the wall, as defined by failure under load or transmission of high temperatures to the unexposed side, had been reached (Table 15). For some of the earlier tests the exposure was continued for

[23] Appendix C, p. 330.

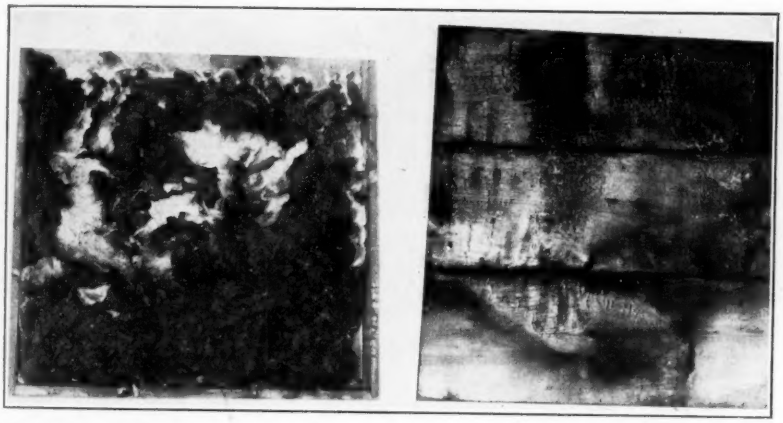


FIG. 17.—*Condition of a cotton pad and an excelsior-filled box after being in contact with the unexposed side of a wall during fire exposure*

six hours, which was considerably beyond the limit of 8 and 12 inch unplastered walls as it concerns the temperature rise on the unexposed side. These tests, however, gave important information on the behavior of such walls when exposed to fires beyond their rated resistance.

The wall was left in place until cooled. The cooling of the furnace chamber was accelerated after the end of the test by air from the fan or compressor for periods from ½ to 2 hours, depending on the length of the preceding firing periods. In other tests the fire was shut off at ¾, 1½, or 3 hours to determine the extent of the fire damage for these exposure periods. Only one test (No. 92) was stopped due to equipment trouble before the fire-resistance period of the wall had been attained.

In the fire and water tests the walls were subjected to one hour of the fire-endurance tests and then withdrawn from the furnace, when a hose stream at a given pressure and for a given duration was applied over the heated side.

(a) LOADING

For walls tested under load, 120 lbs./in.^{2} of gross bearing area was generally applied to end-construction tile, and 80 lbs./in.^{2} to side-construction tile, with exceptions as noted in Table 9. The load was maintained constant throughout the test. In most cases overloads, usually 50 per cent and sometimes 100 per cent above the constant load, were applied after the fire had been stopped. This load with the overload (see log of tests) was usually applied again after the wall had cooled. The openings at the ends and the top of the unrestrained walls and at the ends of the loaded walls were stopped with a strip of metal lath bent into U shape, placed in the openings, and plastered on the exposed side with gypsum plaster. In this way the openings were stopped to the passage of flame without making the load indeterminate.

(B) FIRE EXPOSURE

The fire was regulated to obtain average indicated furnace temperatures of near 843° C. (1,550° F.) at 30 minutes, 927° C. (1,700° F.) at 1 hour, 1,010° C. (1,850° F.) at 2 hours, 1,093° C. (2,000° F.) at 4 hours, 1,177° C. (2,150° F.) at 6 hours, 1,260° C. (2,300° F.) at 8 hours, and 1,371° C. (2,500° F.) at 10 hours 40 minutes, the latter temperature being maintained as constant as possible for the remainder of tests extending beyond this time. The standard reference curve is shown in dashed lines in Figures 56 to 186. The rate of cooling of the furnace is also shown on some of these graphs. The air was generally left on for about 30 minutes after the fire was stopped.

TABLE 15.—*Test conditions*

8-INCH WALLS OF SHALE TILE

No.	Wall: Type	Wall: Size (feet)	Plaster [1]: Exposed side	Plaster [1]: Unexposed side	Date tested	Age at test	Furnace exposure: Up to one-half hour	Furnace exposure: Up to end of test	Test duration	Reason for ending test	Restraint or load during test	Load applied at end of test	Load applied after cooling	Strength of masonry, specimen after fire
						Days	*Per cent*	*Per cent*	*H. m.*		*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*
1	8-A-E	4 by 4	None	None	May 4, 1922	30	105.9	98.5	6 00	Set time limit	120			
2	do	8 by 10½	do	do	June 30, 1925	32	92.9	95.2	2 51	250° C. temperature	120			
3	do	do	do	do	do	32	90.7	96.5	2 51	do	120			
4	do	16 by 10½	do	do	Oct. 27, 1925	48	94.6	99.7	2 17	150° C. temperature	80	120	120	
[2] 5	do	do	Gunite 1:½:3	do	Jan. 22, 1926	32			5 07	do	80	120	120	
6	do	16 by 11	None	do	Oct. 21, 1924	32	96.0	102.6	2 53	250° C. temperature	[3]			300
7	do	4 by 4	do	do	Sept. 1, 1922	51	99.3	99.9	6 00	Set time limit	120			
8	8-A-S	8 by 10½	Gypsum	do	July 20, 1926	54	94.4	96.9	3 06	150° C. temperature	80	120		275
9	8-A-E	do	do	Gypsum	Oct. 23, 1925	42	95.6	99.2	5 30	do	80	120	120	
[2] 10	do	do	do	do	Jan. 29, 1926	32			5 30	Previous test limit	80	120	120	
11	do	4 by 4	None	None	Aug. 10, 1922	44	95.0	99.4	1 30	Set time limit	[4]			
12	do	do	Gypsum [5]	Gypsum [5]	Aug. 2, 1922	89	102.4	99.5	1 30	do	[4]			
13	8-AI-E	do	do	do	June 16, 1926	49	113.4	100.5	5 01	Subsequent temperature	[4]			
14	do	do	do	do	Aug. 11, 1926	35	90.0	100.1	6 06	139° C. temperature rise	[4]			
15	8-E-E	8 by 10½	do	do	Oct. 23, 1925	42	93.8	100.5	5 30	150° C. temperature	80	120	120	
[2] 16	do	do	do	do	Jan. 29, 1926	32			5 30	Previous test limit	80	120	120	
17	8-K-S	4 by 4	None	None	Nov. 24, 1922	45	96.9	98.4	1 32	Load failure	80	[6] 95		
18	8-L-S	do	do	do	May 17, 1926	92	96.1	98.7	2 15	139° C. temperature rise	80	[6] 110		
19	8-O-S	do	do	do	Mar. 8, 1923	45	88.9	95.8	1 30	Set time limit	80		80	
20	do	do	do	do	Mar. 22, 1923	29	95.2	97.1	1 30	do	80			
21	do	8 by 10½	do	do	May 26, 1925	30	93.2	96.2	4 25	Air compressor shut down	80	[5] 112		
22	8-P-S	4 by 4	do	do	Feb. 23, 1923	53	97.0	99.6	6 00	Set time limit	80		[6] 70	
23	do	do	do	do	Apr. 18, 1923	35	98.0	98.7	1 30	do	80		80	
24	8-Q-S	do	do	do	Sept. 1, 1926	55	97.7	100.4	2 23	139° C. temperature rise	80	120	[6] 104	
25	do	8 by 10½	Gypsum	do	July 20, 1926	54	91.9	97.6	3 06	139° C. temperature rise (on companion wall).	80	120	120	280
26	8-R-S	4 by 4	None	do	June 26, 1925	48	97.6	100.0	3 12	250° C. temperature	80	120	[6] 30	
27	do	do	Gypsum	do	May 10, 1925	34	99.5	100.0	6 00	Set time limit	80	120	120	
28	8-T-S	do	None	do	June 9, 1925	31	98.3	98.7	3 56	250° C. temperature	80	120		
29	do	do	Gypsum	do	July 30, 1925	105	107.0	101.1	4 43	do	80	120		
30	8-S-S	do	None	do	June 11, 1925	33	109.4	101.9	3 36	do	80		120	
31	do	do	Gypsum	do	Aug. 8, 1925	124	100.6	99.4	6 00	Set time limit	80	120	120	

8-INCH WALLS OF SURFACE-CLAY TILE

32	8-A-E	4 by 4	None	None										

8-INCH WALLS OF SURFACE-CLAY TILE

31	....do....	....do....	Gypsum	....do....	Aug. 8, 1925	42								
32	8-A-E	4 by 4	None	None	Oct. 10, 1922	34	98.1	101.6	1 37	Load failure	[6] 120			
33	....do....	....do....	....do....	....do....	Nov. 7, 1922	61	97.2	98.8	1 30	Set time limit	120			
34	8-C-E	8 by 10½	....do....	....do....	Sept. 4, 1925	36			0 45	Load failure	[6] 120			
35	....do....	....do....	....do....	....do....	....do....	36			0 45	....do....	[5] 120			
36	....do....	8 by 11	Gypsum	....do....	Sept. 18, 1925	43	96.6	99.5	6 00	Set time limit	(4)			350
37	....do....	....do....	Cement	Cement	....do....	43	96.4	98.4	6 00	....do....	(4)			255
38	....do....	8 by 10½	None	None	July 9, 1926	42	86.7	97.4	3 31	139° C. temperature rise	70	105	120	160
39	....do....	....do....	Gypsum	....do....	....do....	42	83.8	98.0	3 31	139° C. temperature rise (on companion wall).	70	105	120	195
40	8-A-E	4 by 4	None	....do....	May 7, 1923	28	102.5	102.5	0 33	Load failure	[6] 120			
41	....do....	....do....	....do....	....do....	May 8, 1923	29	93.5	98.1	1 30	Set time limit	120			
42	8-B-E	16 by 11	....do....	....do....	June 23, 1924	28	94.2	98.7	4 12	250° C. temperature	[3]			220
43	....do....	8 by 10½	....do....	....do....	Aug. 19, 1925	33	88.3	98.9	3 51	....do....	120	180	120	
44	....do....	....do....	....do....	....do....	....do....	33	89.2	98.7	3 51	....do....	120	180	180	
45	....do....	8 by 11	Gypsum	....do....	Mar. 31, 1925	34	100.5	97.9	6 00	Set time limit	(4)			380
46	....do....	....do....	Cement 1:3 plus 15 per cent lime.	Cement 1:3 plus 15 per cent lime.	....do....	34	92.3	98.9	6 00	....do....	(4)			215
47	8-B-E	4 by 4	None	None	Aug. 24, 1922	22	110.1	102.6	1 30	....do....	(4)			
48	....do....	....do....	Cement 1:2½	Cement 1:2½	July 27, 1922	80	105.1	102.2	1 30	....do....	(4)			
49	....do....	....do....	Gypsum [5]	Gypsum [5]	July 26, 1922	79	106.1	101.1	1 30	....do....	(4)			
50	....do....	....do....	Lime	Lime	July 29, 1922	82	103.0	100.6	1 30	....do....	(4)			
51	....do....	....do....	Cement-lime 1:½:4.	None	Nov. 17, 1922	71	102.0	101.5	1 30	....do....	(4)			
52	....do....	....do....	Cement-lime 1:1:5.	....do....	Dec. 8, 1922	92	98.0	100.5	1 30	....do....	(4)			
53	....do....	....do....	Cement-lime 1:2:7.	....do....	Feb. 7, 1923	70	102.3	100.1	1 30	....do....	(4)			
54	....do....	....do....	Lime	....do....	Feb. 6, 1923	69	98.9	99.2	1 30	....do....	(4)			
55	....do....	....do....	....do....	....do....	Dec. 18, 1923	384			1 30	....do....	(4)			
56	....do....	....do....	Cement 1:2½ [7]	....do....	Oct. 27, 1922	56	101.5	101.8	1 30	....do....	(4)			
57	....do....	....do....	Cement 1:3 plus 15 per cent lime.	....do....	Feb. 8, 1923	71	101.8	100.9	1 30	....do....	(4)			
58	....do....	....do....	Gypsum [5]	....do....	Nov. 20, 1922	43	102.8	101.5	1 30	....do....	(4)			
59	....do....	....do....	....do. [9]	....do....	Nov. 21, 1922	44	93.8	99.3	1 30	....do....	(4)			
60	8-O-S	8 by 10½	None	....do....	May 26, 1925	30	89.5	98.1	4 25	Air compressor shut down	80	120	80	110
61	8-K-S	4 by 4	....do....	....do....	Mar. 4, 1926	49	94.2	102.1	3 21	150° C. temperature	80	120	120	

[1] All plaster 1:3 volume parts calcined gypsum, Portland cement, or hydrated lime and sand applied in two body coats unless otherwise indicated.
[2] Repaired walls subjected to second test.
[3] Unrestrained.
[4] Restrained.
[5] Two coats of 1:3 plaster plus finish coat of 1:1 lime putty and calcined gypsum.
[6] Failed under this load.
[7] One coat.
[8] One coat 1:3 plaster plus finish coat of plastic gypsum.
[9] Two coats 1:3 plaster plus finish coat of plastic gypsum.

105591°—28——6

TABLE 15.—*Test conditions*—Continued

8-INCH WALLS OF SURFACE-CLAY TILE—Continued

No.	Wall: Type	Wall: Size (feet)	Plaster: Exposed side	Plaster: Unexposed side	Date tested	Age at test	Furnace exposure: Up to one-half hour	Furnace exposure: Up to end of test	Test duration	Reason for ending test	Restraint or load during test	Load applied at end of test	Load applied after cooling	Strength of masonry specimen after fire
						Days	*Per cent*	*Per cent*	*H. m.*		*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in².*
62	8-L-S	4 by 4	None	None	Mar. 2, 1926	47	98.8	100.5	2 22	150° C. temperature	80	120	120	
63	do	do	do	do	May 19, 1926	56	103.0	102.2	1 38	do	80	120	80	
64	8-U-S	do	do	do	May 17, 1926	69	112.9	101.8	2 42	do	80		80	
65	8-O-S	do	do	do	May 25, 1923	28	93.2	100.3	6 00	Set time limit	80			
66	do	do	do	do	May 26, 1923	29	97.0	97.6	0 45	do	80			
	8-INCH WALLS OF FIRE-CLAY TILE													
67	8-A-E	16 by 11	None	None	Apr. 1, 1924	41	110.2	100.9	6 00	Set time limit	(3)			250
68	do	do	Gypsum	Gypsum	Apr. 15, 1924	49	96.1	100.0	6 00	do	(4)			320
69	do	8 by 10½	None	None	Nov. 18, 1924	33	98.2	99.1	6 00	do	120		120	
70	do	do	Gypsum	Gypsum	do	33	99.3	99.1	6 00	do	120		120	
71	do	8 by 11	None	None	Mar. 24, 1926	57	91.2	99.9	4 40	139° C. temperature rise (on companion wall).	(4)			280
72	do	do	Gypsum	Gypsum	do	57	78.3	98.0	4 40	139° C. temperature rise	(4)			410
73	do	4 by 4	None	None	Aug. 18, 1922	32	93.7	99.5	6 00	Set time limit	120		120	
[10] 73a	do	do	do	do	Jan. 4, 1927	39	104.6	101.7	1 26	139° C. temperature rise	120			
74	do	8 by 10½	do	do	Apr. 10, 1925	29	97.5	101.1	3 01	250° C. temperature	120	157	120	
75	do	do	do	do	do	29	91.1	102.0	3 01	do	120	157	120	
76	do	16 by 11	do	do	May 27, 1924	31	96.5	102.1	6 00	Set time limit	(4)			215
77	do	8 by 11	Gypsum	do	May 12, 1925	36	75.1	98.6	5 42	250° C. temperature	(4)			395
78	do	do	Cement 1:3 plus 15 per cent lime.	do	do	36	75.1	98.6	5 42	do	(4)			180
79	8-A-S	8 by 10½	None	do	Mar. 12, 1926	32	91.1	97.8	2 00	150° C. temperature	80	120	[6] 120	160
80	do	do	Gypsum	Gypsum	do	32	99.9	100.9	2 00	150° C. temperature (on companion wall).	80	120	120	265
81	do	8 by 11	None	None	Mar. 6, 1926	32	83.7	98.4	4 10	do	(4)			
82	do	do	Gypsum	Gypsum	do	32	106.2	103.0	4 10	150° C. temperature	(4)			230
83	8-B-E	4 by 4	None	None	Aug. 8, 1922	42	92.8	97.7	1 30	Set time limit	(4)			
84	do	do	Gypsum [5]	Gypsum [5]	July 19, 1922	77	113.6	104.8	1 39	do				
85	do	8 by 11	Cement 1:3	None										

84	....do....	....do....	Gypsum [5]	Gypsum [5]	July 19, 1922	77	113.6	104.8	1	30	....do....	(4)			
85	....do....	8 by 11	Cement 1:3 plus 15 per cent lime.	None	Mar. 3, 1925	36	82.7	98.7	6	00	....do....	(4)			265
86	....do....	....do....	Gypsum	Gypsum	....do....	36	72.3	95.6	6	00	....do....	(4)			385
87	....do....	....do....	....do....	....do....	Oct. 7, 1926	135	95.9	97.0	3	30	Subsequent temperature	(4)			
88	8-BI-E	....do....	....do....	None	....do....	135	74.3	96.4	3	30	....do....	(4)			
89	8-D-E	....do....	None	....do....	Aug. 4, 1925	32	102.9	99.2	6	00	Set time limit	(4)			265
90	....do....	....do....	Gypsum	Gypsum	....do....	32	98.9	97.8	6	00	....do....	(4)			385
91	8-E-E	4 by 4	None	None	Feb. 28, 1923	33	90.3	99.2	6	00	....do....	120		160	
92	....do....	....do....	....do....	....do....	Mar. 14, 1923	48	86.2	95.4	1	05	Air compressor shut down	120			
93	....do....	....do....	....do....	....do....	May 2, 1923	33	95.7	99.6	6	00	Set time limit	120			
94	8-K-S	....do....	....do....	....do....	Mar. 20, 1926	94	95.1	98.0	2	42	139° C. temperature rise	80	120	120	
95	....do....	8 by 11	....do....	....do....	Jan. 14, 1925	36	90.2	98.0	4	07	250° C. temperature	(3)			250
96	....do....	....do....	Gypsum	Gypsum	July 14, 1925	67	83.6	96.7	6	00	Set time limit	(4)			230
97	8-L-S	....do....	None	None	Jan. 14, 1925	36	89.0	95.3	4	07	250° C. temperature	(3)			210
98	....do....	....do....	Gypsum	Gypsum	July 14, 1925	67	80.7	96.9	6	00	Set time limit	(4)			250
99	8-K-S	4 by 4	None	None	Apr. 16, 1926	38	112.7	103.2	2	11	139° C. temperature rise	80	120	120	
101	8-O-S	....do....	....do....	....do....	May 12, 1923	30	101.4	100.1	6	00	Set time limit	80		80	
102	....do....	....do....	....do....	....do....	May 11, 1923	29	102.8	101.1	1	30	....do....	80			
103	8-P-S	....do....	....do....	....do....	Mar. 30, 1923	32	98.1	99.3	6	00	....do....	80			
104	....do....	....do....	....do....	....do....	Mar. 28, 1923	30	97.7	99.3	1	30	....do....	80			
105	....do....	8 by 11	....do....	....do....	Jan. 13, 1926	62	99.7	99.3	6	00	....do....	(4)			275
106	....do....	....do....	Gypsum	Gypsum	....do....	62	112.6	100.9	6	00	....do....	(4)			340
107	8-Q-S	4 by 4	None	None	Oct. 29, 1925	42	104.6	100.1	3	23	250° C. temperature	80	120	120	
108	....do....	....do....	Gypsum	Gypsum	Dec. 18, 1925	35	92.3	100.1	4	53	139° C. temperature rise	80	120	120	
109	8-Q-E	....do....	....do....	....do....	Dec. 15, 1925	32	99.5	100.7	4	45	....do....	120	180	180	
110	10-H-S	8 by 10½	....do....	Cement 1:3 plus 15 per cent lime.	Mar. 26, 1926	34	83.8	96.1	4	02	....do....	110	165	165	210
111	10-N-S	....do....	....do....	....do....	....do....	34	86.0	97.5	4	02	....do....	110	165	165	340
112	8-MZ-S	....do....	....do....	Brick	Mar. 13, 1925	30	97.2	100.4	5	31	....do....	80	120	120	530
113	8-JZ-E	....do....	....do....	....do....	....do....	30	89.5	98.6	5	31	....do....	80	120	180	575

12-INCH WALLS OF SHALE TILE

114	12-A-E	4 by 4	None	None	June 2, 1923	30	99.0	99.4	6	00	Set time limit	120			
115	....do....	....do....	....do....	....do....	June 11, 1923	37	93.9	99.0	3	00	....do....	120		120	
116	12-AH-E	....do....	....do....	....do....	July 18, 1923	28	100.6	100.3	6	00	....do....	120		120	
117	....do....	....do....	....do....	....do....	July 23, 1923	33	102.5	99.6	3	00	....do....	120		120	
118	12-O-S	8 by 10½	....do....	....do....	Apr. 20, 1926	34	90.9	98.0	5	00	....do....	80	120		150

[3] Unrestrained.
[4] Restrained.
[5] Two coats of 1:3 plaster plus finish coat of 1:1 lime putty and calcined gypsum.
[6] Failed under this load.
[10] Was dried to nearly constant weight before testing.

TABLE 15.—*Test conditions*—Continued

12-INCH WALLS OF SURFACE-CLAY TILE

No.	Wall: Type	Wall: Size (feet)	Plaster: Exposed side	Plaster: Unexposed side	Date tested	Age at test	Furnace exposure: Up to one-half hour	Furnace exposure: Up to end of test	Test duration	Reason for ending test	Restraint or load during test	Load applied at end of test	Load applied after cooling	Strength of masonry specimen after fire
						Days	*Per cent*	*Per cent*	*H. m.*		*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*
119	12-C-E	4 by 4	None	None	Nov. 3, 1923	22	101.1	99.4	4 10	Load failure	[5] 120			
120	12-CH-E	do	do	do	Aug. 24, 1926	47	100.0	101.5	5 23	139° C. temperature rise	80	[5] 87		
121	do	do	do	do	Dec. 12, 1923	61	104.0	100.1	6 00	Set time limit	120			
122	do	do	do	do	Dec. 6, 1923	55	99.5	99.3	3 00	do	120			
123	do	8 by 10½	do	do	May 25, 1926	50	102.0	96.4	2 22	Load failure	[6] 80			
124	12-BJ-E	do	do	do	May 7, 1926	32	90.8	100.7	5 00	139° C. temperature rise	80	120		
125	12-O-S	4 by 4	do	do	Aug. 10, 1926	34	94.9	100.5	8 33	do	80			
[10] 125a	do	do	do	do	Feb. 2, 1927	68	92.5	99.8	5 43	do	80	120	120	
126	do	do	Gypsum	Gypsum	July 27, 1926	60	104.5	101.4	10 42	do	80		120	
127	do	8 by 10½	None	None	Apr. 20, 1926	34	82.5	82.6	5 00	Set time limit	80	120		85
128	do	do	do	do	July 21, 1925	48	87.1	96.5	6 00	do	80	120	80	
129	do	do	Gypsum	Gypsum	do	48	92.9	96.5	6 00	do	80	120	80	120

12-INCH WALLS OF FIRE-CLAY TILE

130	12-A-E	4 by 4	None	None	Sept. 10, 1923	41	99.7	99.2	6 00	Set time limit	120		120	
131	do	do	do	do	Sept. 6, 1923	36	102.7	99.9	3 00	do	120		120	
132	do	16 by 11	do	do	Sept. 4, 1924	41	94.6	97.4	6 00	do	[3]			190
133	12-AH-E	4 by 4	do	do	Oct. 24, 1923	28	101.4	100.5	6 00	do	120			
[10] 133a	do	do	do	do	Feb. 8, 1927	74	93.8	99.6	3 38	139° C. temperature rise	120	180	[6] 160	
134	do	do	do	do	Sept. 12, 1923	42	102.9	100.7	3 00	Set time limit	120			
135	12-G-E	8 by 11	do	do	Jan. 15, 1926	42	96.2	99.1	6 00	do	[4]			195
136	do	do	Gypsum	Gypsum	do	42	96.7	97.2	6 00	do	[4]			235
137	12-P-S	4 by 4	None	None	Aug. 18, 1926	42	94.9	100.6	5 05	139° C. temperature rise	80	120	120	
138	do	do	Gypsum	Gypsum	Aug. 26, 1926	43	102.2	100.7	8 34	do	80	120	120	
139	12-Q-S	do	None	None	Dec. 22, 1925	35	97.7	99.7	5 32	do	80		[6] 100	
140	do	do	Gypsum	Gypsum	Dec. 16, 1925	32	103.2	99.4	8 15	do	80		120	
141	12-WXZ-E	do	None	Brick	Oct. 12, 1926	28	106.8	100.5	4 00	Set time limit	100	175	175	
142	do	do	Gypsum	do	Oct. 27, 1926	43	103.9	100.9	4 00	do	100	175	175	
143	do	do	Brick	None	Oct. 16, 1926	32	94.9	99.4	4 00	do	100	175	175	
144	do	do	Gypsum	Brick	Dec. 10, 1926	29	92.9	100.6	2 00	do	100	175	175	
145	12-WY-E	do	do	None	Dec. 11, 1926	30	94.0	95.5	1 00	do	100	175	175	
146	12-LM-S	8 by 10½	do	Brick	May 22, 1925	37	98.5	98.5	6 00	do	100	175	175	
147	12-WXZ-E	do	do	do	Dec. 14, 1926	33	94.9	99.4	4 00	do	100	175	175	

144	....do....	....do....	Gypsum	Brick	Dec. 10, 1926	29	92.9	100.6	2	00	....do....	100	175	175	
145	12-WY-E	....do....	....do....	None	Dec. 11, 1926	30	94.0	98.5	1	00	....do....	100	175	175	
146	12-LM-S	8 by 10⅓	....do....	Brick	May 22, 1925	37	98.5	98.5	6	00	....do....	80	120	160	220
147	12-VXZ-E	....do....	....do....	....do....	....do....	37	91.2	97.5	6	00	....do....	80	120	160	360
					16-INCH WALL OF SHALE TILE										
148	16-AH-E	16 by 11	None	None	Dec. 16, 1924	49	92.4	93.9	5	11	Fallen shells obstructed burners.	(4)			
					16-INCH WALLS OF SURFACE-CLAY TILE										
149	16-O-S	4 by 4	None	None	Aug. 2, 1926	66	105.2	100.2	13	48	139° C. temperature rise	80		120	
150	....do....	....do....	Gypsum	Gypsum	July 15, 1926	48	102.4	100.5	18	10	....do....	80		80	
					16-INCH WALLS OF FIRE-CLAY TILE										
151	16-AH-E	16 by 11	None	None	Feb. 10, 1925	34	101.1	100.1	6	00	Set time limit	(4)			180
152	....do....	....do....	....do....	....do....	Apr. 24, 1925	42	92.8	99.3	6	00	....do....	(3)			165
153	....do....	4 by 4	....do....	....do....	June 2, 1926	35	112.5	100.9	6	50	Subsequent temperature	150		[6] 157	
154	....do....	....do....	Gypsum	Gypsum	June 29, 1926	63	111.5	100.8	9	24	....do....	150		180	
155	16-LM-S	8 by 11	None	None	Sept. 3, 1924	39	87.1	97.3	6	00	Set time limit	(4)			130
156	16-KM-S	....do....	....do....	....do....	....do....	39	88.6	96.8	6	00	....do....	(4)			120
157	....do....	4 by 4	....do....	....do....	July 2, 1926	65	98.2	100.4	8	45	Subsequent temperature	80	120	120	
158	....do....	....do....	Gypsum	Gypsum	July 12, 1926	75	103.8	100.6	12	33	Load failure	[6] 80			
159	16-P-S	16 by 11	None	None	Aug. 5, 1924	41	84.9	97.4	6	00	Set time limit	(4)			
160	....do....	4 by 4	....do....	....do....	Aug. 20, 1926	26	98.4	100.9	10	54	139° C. temperature rise	80	120	120	
[10] 160a	....do....	....do....	....do....	....do....	Jan. 27, 1927	62	97.8	100.0	9	03	....do....	80			
161	....do....	....do....	Gypsum	Gypsum	Aug. 13, 1926	37	101.1	99.7	14	16	....do....	80		[6] 80	
162	16-Q-S	....do....	None	None	June 21, 1926	54	109.5	100.2	7	01	Subsequent temperature	100		[6] 100	
163	....do....	....do....	Gypsum	Gypsum	Feb. 25, 1926	45	104.3	99.6	12	45	139° C. temperature rise	(4)			
164	16-WYZ-E	....do....	....do....	Brick	Oct. 9, 1926	25	109.3	100.8	4	00	Set time limit	100	225	225	

[3] Unrestrained.
[4] Restrained.
[6] Failed under this load.
[10] Was dried to nearly constant weight before testing.

(c) OBSERVATIONS DURING TEST

In addition to the temperature and deflection readings, which were taken at from 5 to 15 minutes intervals, depending upon the rate of change, notes of the fire effects and cracking of the wall were made.

(d) OBSERVATIONS AFTER TEST AND DURING DISMANTLING OF THE WALL

After the walls were cool, their general condition was noted and the deflection measured. For the walls tested under load, the load and, in some cases, the overload were again applied and the behavior of the walls noted.

In dismantling the walls each tile was inspected to determine whether the shells were loose and whether the webs were cracked, and, if so, the extent of the damage.

(e) COMPRESSION TESTS OF MASONRY SPECIMENS

At the time of dismantling the large walls, small masonry sections of size comparable with those built at the time of building the walls were cut from most of the fire-tested walls and tested in compression. Their strength, in comparison with the strength of those not subjected to fire exposures, gave, in a general way, a measure of the loss in strength due to the fire exposure. It is apparent that this is not an accurate measure of the loss in strength because of the variation in strength of individual sections or parts of walls (only one specimen being taken for or from each wall) and because of damage incurred in cutting them from the tested wall and subsequent handling. There is also some doubt as to whether the relative strength of wall sections 3 feet high is comparable with that of walls story height.

(f) PHOTOGRAPHIC RECORDS

Photographs of the exposed side and, in some cases, of the unexposed side were made both before and after the fire exposure. In cases where the appearance of the wall was similar to one already photographed or where no important changes had taken place during the test, photographs were not taken.

(g) FIRE AND WATER TEST PROCEDURE

The walls to be subjected to the fire and water test were first subjected to one hour of the regular fire exposure. At its conclusion the wall was removed from the furnace, this requiring from one to two minutes, and water from a hose stream was applied to the hot side through a standard 1⅛-inch play pipe. The nozzle was stationed 19 feet from the wall to meet the requirement of 20 feet from the center of the wall with a deduction of 1 foot for each 10° deviation from the perpendicular to the center of the wall.[24] For these tests the nozzle was stationed on a level with the bottom of the wall, or

[24] Appendix C, p. 330.

about 10° below a line normal to its center. The water pressure at the base of the nozzle and the duration of the application conformed with the present American Engineering Standards Committee tentative specifications for the conduct of fire tests as applied to wall constructions of the range in fire resistance developed in this series of tests.[24]

11. RESULTS OF FIRE-ENDURANCE TESTS

The main results of the fire tests are summarized in Tables 15, 16, and 17, and Figures 19 and 20. The principal points brought out in these tables and figures are the relative severity of the fire exposure for each test, the lateral deflections, the load-carrying ability, and the temperature rise on the unexposed surface.

(a) CONDITION OF WALLS AFTER FIRE-ENDURANCE TESTS

The condition of some of the walls after test is shown in Figures 21 to 52. Although photographs of nearly all of the walls were taken both before and after test, only a few are reproduced in this paper. Only those are published which show typical or unusual effects. Where the photographs are not published because of similarity to some others, reference is made in the log of a number of the tests to a figure showing similar effects.

A detailed description of the condition of the walls after the fire tests is given in the log of tests (pp. 101 to 155).

(b) FURNACE TEMPERATURES

The maximum, minimum, and average temperatures of the furnace as indicated by six couples are shown by the upper curves of the time-temperature plots (figs. 56 to 186). In general, only the average furnace temperatures were plotted for the tests in the small furnace. In each time-temperature plot the standard reference curve [24] is also given. The difference in temperature between the maximum and the minimum and the deviation of the average from the standard is larger during the first 30 to 45 minutes than for subsequent periods, especially for the tests of the large walls.

A comparative measure of the furnace exposure was obtained by comparing the measured area under the average furnace temperature curve for a given test with the area under the standard reference curve for the same period, which was taken as unity. The percentage exposure thus determined for the first one-half hour and for the duration of the test is given in Table 15. The exposure for the initial period is given, since the fire effects on tile are more dependent upon the rate of temperature rise than on the temperature attained later in the tests.

The furnace temperature average for the large tests and the small tests, together with the reference curve, is shown in Figure 18.

[24] Appendix C, p. 330.

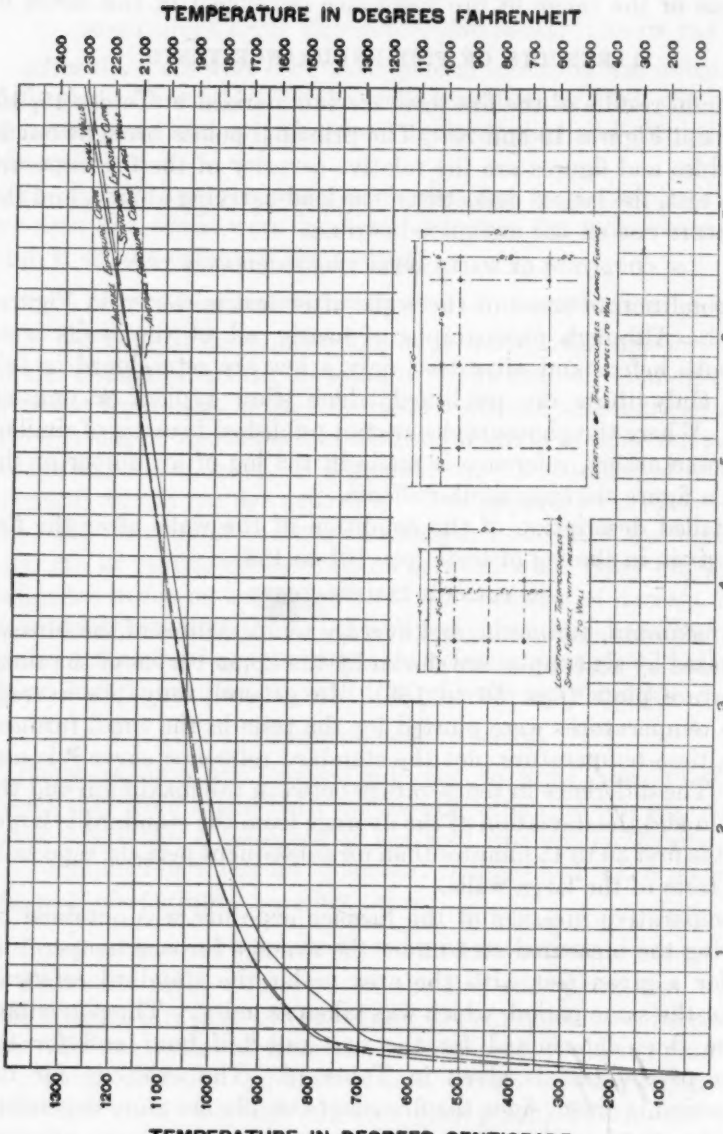


FIG. 18.—*Average furnace temperatures compared with standard furnace temperatures*

TABLE 16.—*Lateral deflections of large walls*

8-INCH WALLS OF SHALE TILE

Wall				Maximum deflections (inches)				
				At center of wall			At middle of top of wall	
No.	Type	Size (feet)	Restraint or load	Inward during test	After cooling		Outward during test	Outward after cooling
					In	Out		
			Lbs./in.[2]					
2	8-A-E	8 by 10⅓	120	1.40				
3	do	do	120	1.40				
4	do	16 by 10⅓	80	1.45		0.50		
6	do	16 by 11	Unrestrained.				6.25	2.60
8	8-A-S	8 by 10⅓	80	1.35		.20		
9	8-A-E	do	80	1.05	0.05			
15	8-E-E	do	80	.75		.50		
21	8-O-S	do	80	.70				
25	8-Q-S	do	80	1.50		.25		

8-INCH WALLS OF SURFACE CLAY TILE

36	8-C-E	8 by 11	Restrained.	1.10	0.10			
37	do	do	Restrained.	1.25	.25			
38	do	8 by 10⅓	70	1.00		0.20		
39	do	do	70	1.05		.30		
42	8-B-E	16 by 11	Unrestrained.				3.90	2.00
43	do	8 by 10⅓	120	.80		.55		
44	do	do	120	1.30		.25		
45	do	8 by 11	Restrained.	1.40	.20			
46	do	do	Restrained.	1.40	.00			
60	8-O-S	8 by 10⅓	80	.75		.60		

8-INCH WALLS OF FIRE CLAY TILE

68	8-A-E	16 by 11	Restrained.	1.30	0.10			
69	do	8 by 10⅓	120	.75		0.45		
70	do	do	120	1.00		.10		
71	do	8 by 11	Restrained.	.60	.00			
72	do	do	Restrained.	.80	.00			
74	do	8 by 10⅓	120	1.25		.50		
75	do	do	120	1.10		.60		
76	do	16 by 11	Restrained.	1.45		.10		
77	do	8 by 11	Restrained.	1.45	.30			
78	do	do	Restrained.	1.25	.20			
79	8-A-S	8 by 10⅓	80	1.40		.05		
80	do	do	80	1.10	.00			
81	do	8 by 11	Restrained.	1.25	.25			
82	do	do	Restrained.	1.60	.40			
85	8-B-E	do	Restrained.	1.10	.10			
86	do	do	Restrained.	1.00	.20			
87	do	do	Restrained.	1.00	.45			
88	8-BI-E	do	Restrained.	.90	.10			
89	8-D-E	do	Restrained.	1.35	.40			
90	do	do	Restrained.	1.25	.60			
96	8-K-S	do	Restrained.	1.30	.20			
98	8-L-S	do	Restrained.	1.10	.00			
105	8-P-S	do	Restrained.	1.00		.25		
106	do	do	Restrained.	1.00	.00			
110	10-H-S	8 by 10⅓	110	1.05	.10			
111	10-N-S	do	110	1.20	.40			
112	8-MZ-S	do	80	.90		.25		
113	8-JZ-E	do	80	.95		.05		

FIG. 18.—*Average furnace temperatures compared with standard furnace temperatures*

TABLE 16.—*Lateral deflections of large walls*—Continued

12-INCH WALL OF SHALE TILE

No.	Wall: Type	Wall: Size (feet)	Restraint or load	Maximum deflections (inches): At center of wall: Inward during test	At center of wall: After cooling: In	At center of wall: After cooling: Out	At middle of top of wall: Outward during test	At middle of top of wall: Outward after cooling
			*Lbs./in.*²					
118	12-O-S	8 by 10½	80	0.75				
	12-INCH WALLS OF SURFACE CLAY TILE							
123	12-CH-E	8 by 10½	80	0.20				
124	12-BJ-E	do	80	.40		0.65		
127	12-O-S	do	80	.60				
128	do	do	80	.40		.75		
129	do	do	80	.30		.50		
	12-INCH WALLS OF FIRE CLAY TILE							
132	12-A-E	16 by 11	Unrestrained.				5.25	1.75
135	12-G-E	8 by 11	Restrained.	0.90	0.05			
136	do	do	Restrained.	.60		0.10		
146	12-LMZ-E	8 by 10½	80	.70		.55		
147	12-VXZ-E	do	80	.90		.30		
	16-INCH WALL OF SHALE TILE							
148	16-AH-E	16 by 11	Restrained.	0.90	0.00			
	16-INCH WALLS OF FIRE CLAY TILE							
151	16-AH-E	16 by 11	Restrained.	1.00	0.30			
152	do	do	Unrestrained.				3.40	0.60
155	16-LM-S	8 by 11	Restrained.	.90	.20			
156	16-KM-S	do	Restrained.	1.00	.25			
159	16-P-S	16 by 11	Restrained.	.90	.00			

A discussion of the significance of the furnace temperatures as measured with protected couples is given in Bureau of Standards Technologic Paper No. 184, Fire Tests of Building Columns, pages 101 to 106. The temperatures indicated by thermocouples protected by mountings, such as those used in these tests, are lower than if measured with unprotected couples, particularly during the first 20 to 30 minutes of the test. While unprotected couples indicate the temperature of the furnace gases more closely than those within the mountings that need to be used to prevent changes in the thermoelectric properties of the couple during the test, the general purpose of furnace control and duplication of fire exposures for the different tests is believed to be better attained with the use of the protected thermocouples.

(c) WALL TEMPERATURES

The temperatures measured at various points in the wall are given by the intermediate curves on the time-temperature plots. Each group represents the maximum, average, and minimum temperatures measured by three or more couples similarly placed at an equal distance from the exposed surface of the wall. The location of each group is shown in the sketches on the curve sheets, which for end-construction tile are plan views and for side-construction tile sectional elevations. These temperatures give important information on the effect of the plaster, the thickness of the shells, and the protection afforded wooden members framed into the walls.

The time required to obtain an average temperature rise of 200° C. (360° F.) approximately 4 inches into the wall from the unexposed side is given in Table 17. This time is regarded as representing the period for which combustible members framed into the wall from the unexposed side would be protected when the wall is not filled at the floor lines opposite and above and below these members.

In a test of a 12-inch hollow-tile wall with wood joists projecting into it 3½ to 4 inches from the unexposed side, ignition of the joist ends occurred when temperatures between 275 and 300° C. (527 to 572° F.) were indicated by thermocouples placed at the ends of the joists. The progress of the fire in the joists was slow, the glow requiring about one and one-half hours to reach the unexposed face of the wall. While joists in old buildings may ignite and burn more readily on account of accumulations of lint and banking up of heat from the floor construction on the unexposed side, a 200° C. (360° F.) average rise seemed a reasonable limit for wall temperatures measured at points where the joist ends would be located. This allows for maximum temperatures at individual points about 30 per cent above this average before ignition of combustible members located at such points would take place.

(d) TEMPERATURES OF UNEXPOSED SURFACE

The temperatures measured on the unexposed surface are given in the lower curves of the time-temperature plots. In all cases the temperatures (*S*) measured with unprotected couples are given, and on about 30 per cent of the total number of plots the temperatures (*P*) under the small asbestos pads are also given. Temperatures under the large cotton or excelsior pads were measured in nearly all of the tests in the large furnace but are shown on plots only where they are higher than those indicated under the small pads or on the free surface. The same applies to temperatures measured at cracks and open joints. The curves marked *R* give room temperatures taken at a point 8 feet in front of the wall, the thermometer being protected against radiation from the wall.

TABLE 17.—*Temperature data from fire-endurance tests*

8-INCH WALLS OF SHALE TILE

No.	Wall: Type	Wall: Size (feet)	Source	Plaster [1]: Exposed side	Plaster [1]: Unexposed side	Test duration	Initial room temperature	Time of 138.9° C. average rise: Under pad	Time of 138.9° C. average rise: On free surface	Time of 180.6° C. maximum rise: Under pad	Time of 180.6° C. maximum rise: On free surface	Temperature rise at end of test: Under pad	Temperature rise at end of test: On free surface	Average temperature rise after test: Under pad: Time	Average temperature rise after test: Under pad: Temperature	Average temperature rise after test: On free surface: Time	Average temperature rise after test: On free surface: Temperature	Time of 200° C. rise 4 inches from unexposed surface
						H. m.	°C.	H. m.	H. m.	H. m.	H. m.	°C.	°C.	H. m.	°C.	H. m.	°C.	H. m.
1	8-A-E	4 by 4	d	None	None	6 00	22	*1 11*	1 24				321					
2	do	8 by 10½	d	do	do	2 51	21	*1 50*	2 11	*1 48*	2 08		240	-- --		3 20	276	1 16
3	do	do	d	do	do	2 51	21	*1 44*	2 04	*1 39*	1 58		230	-- --		3 20	255	1 09
4	do	16 by 10½	d	do	do	2 17	12	*1 48*	2 09	*1 30*	1 47		157	-- --		3 00	213	1 13
[2] 5	do	do	d	Cells filled gunite 1:½:3.	do	5 07												
6	do	16 by 11	d	None	do	2 53	9	*1 27*	1 44	*1 26*	1 42		250	-- --		3 10	260	0 55
7	do	4 by 4	a-1	do	do	6 00	25	*1 24*	1 40				327					0 50
8	8-A-S	8 by 10½	d	Gypsum	do	3 06	23	3 06	3 32	*2 45*	3 16	139	111	4 30	213	4 10	162	2 25
9	8-A-E	do	d	do	Gypsum	5 30	8	*4 25*	5 15	*4 06*	4 53		150	-- --		6 30	185	2 25
[2] 10	do	do	d	do	do	5 30												
11	do	4 by 4	d	None	None	1 30	28						99					0 58
12	do	do	d	Gypsum [3]	Gypsum [3]	1 30	31						42					
13	8-AI-E	do	d	do	do	5 01	22	*5 26*				112	87	7 30	209	7 00	150	3 32
14	do	do	d	do	do	6 06	32	6 05	*6 56*			141	120	8 02	222	7 15	156	3 40
15	8-E-E	8 by 10½	d	do	do	5 30	8	*4 14*	5 02	*2 09*	2 34		162	-- --		6 30	182	1 47
[2] 16	do	do	d	Cells filled	do	5 30												
17	8-K-S	4 by 4	c	None	None	1 32	14			Load failure			71					0 44
18	8-L-S	do	d-2	do	do	2 15	16	*1 49*	2 10				148					1 10
19	8-O-S	do	d-1	do	do	1 30	20						57					1 13
20	do	do	d-1	do	do	1 30	23						60					0 58
21	do	8 by 10½	d-1	do	do	4 25	13	*2 57*	3 31	*3 18*	3 56		193					1 28
22	8-P-S	4 by 4	c-1	do	do	6 00	12	*1 56*	2 18				272					0 49
23	do	do	c-1	do	do	1 30	21						72					0 54
24	8-Q-S	do	d	do	do	2 23	24	2 25	*2 40*			136	104	3 50	252	3 20	184	1 10
25	do	8 by 10½	d	Gypsum	do	3 06	23					80	66	5 30	182	5 15	124	2 11
26	8-R-S	4 by 4	a	None	do	3 12	29	*1 32*	1 50	*1 13*	1 27		264			3 30	272	0 32
27	do	do	a	Gypsum	do	6 00	31	*2 49*	3 21	*2 56*	3 30		225					1 15
28	8-T-S	do	d-3	None	do	3 56	29	*2 23*	2 50	*2 47*	3 19		234			4 30	252	1 52
29	do	do	d-3	Gypsum	do	4 43	30	*2 31*	3 00	*2 52*	3 25		228					2 08
30	8-S-S	do	d-3	None	do	3 36	27	*2 04*	2 23	*2 05*	2 29		231			4 00	245	1 33
31	do	do	d-3	Gypsum	do	6 00	16	*2 35*	3 05	*3 09*	3 45		232			6 30	240	2 05

8-INCH WALLS OF SURFACE-CLAY TILE

8-INCH WALLS OF SURFACE-CLAY TILE

32	8-A-E	4 by 4	*j*	None	None	1	37	21	--	--	--	--	--	--	--	--		58	--	--		--	--		--	--
33	do	do	*j*	do	do	1	30	22	--	--	--	--	--	--	--	--		110	--	--		--	--		1	05
34	8-C-E	8 by 10½	*j*	do	do	0	45	22	Load failure									37	--	--		1	20	52	--	--
35	do	do	*j*	do	do	0	45	22	Load failure									27	--	--		1	20	43	--	--
36	do	8 by 11	*j*	Gypsum	do	6	00	19	*5*	*11*	6	10	*4*	*42*	*5*	36		124	--	--		7	20	172	--	--
37	do	do	*j*	Cement	Cement	6	00	19	6	00+	--	--	--	--	--	--		60	--	--		9	20	94	--	--
38	do	8 by 10½	*j*	None	None	3	31	25	3	27	*4*	*06*	--	--	--	--	145	93	5	00	212	4	45	136	1	32
39	do	do	*j*	Gypsum	do	3	34	25	--	--	--	--	--	--	--	--		49	--	--		5	20	67	2	38
40	8-A-E	4 by 4	*r*	None	do	0	33	22	Load failure									24	--	--		--	--		--	--
41	do	do	*r*	do	do	1	30	24	*1*	*18*	1	33	--	--	--	--		129	--	--		--	--		0	56
42	8-B-E	16 by 11	*k*	do	do	4	12	22	*1*	*58*	2	21	*2*	*08*	2	32		236	--	--		4	30	241	1	18
43	do	8 by 10½	*k*	do	do	3	51	22	*1*	*53*	2	15	*2*	*08*	2	32		216	--	--		4	20	223	1	19
44	do	do	*k*	do	do	3	51	22	*1*	*58*	2	20	*2*	*01*	2	24		235	--	--		4	20	248	1	53
45	do	8 by 11	*k*	Gypsum	do	6	00	10	*5*	*19*	3	57	*4*	*22*	5	12		192	--	--		6	55	206	2	05
46	do	do	*k*	Cement 1:3 plus 15 per cent lime.	Cement 1:3 plus 15 per cent lime.	6	00	10	*5*	*45*	4	28	*4*	*12*	5	00		187	--	--		7	18	202	1	54
47	do	4 by 4	*k*	None	None	1	30	30	--	--	--	--	--	--	--	--		60	--	--		--	--		--	--
48	do	do	*k*	Cement 1:2½	Cement 1:2½	1	30	28	--	--	--	--	--	--	--	--		58	--	--		--	--		--	--
49	do	do	*k*	Gypsum [3]	Gypsum [3]	1	30	28	--	--	--	--	--	--	--	--		40	--	--		--	--		--	--
50	do	do	*k*	Lime	Lime	1	30	30	--	--	--	--	--	--	--	--		42	--	--		--	--		--	--
51	do	do	*k*	Cement-lime 1:½:4	None	1	30	18	--	--	--	--	--	--	--	--		56	--	--		--	--		--	--
52	do	do	*k*	Cement-lime 1:1:5	do	1	30	24	--	--	--	--	--	--	--	--		49	--	--		--	--		--	--
53	do	do	*k*	Cement-lime 1:2:7	do	1	30	14	--	--	--	--	--	--	--	--		42	--	--		--	--		--	--
54	do	do	*k*	Lime	do	1	30	16	--	--	--	--	--	--	--	--		63	--	--		--	--		--	--
55	do	do	*k*	do	do	1	30	14	--	--	--	--	--	--	--	--		47	--	--		--	--		--	--
56	do	do	*k*	Cement [4] 1:2½	do	1	30	24	--	--	--	--	--	--	--	--		60	--	--		--	--		--	--
57	do	do	*k*	Cement 1:3 plus 15 per cent lime.	do	1	30	17	--	--	--	--	--	--	--	--		48	--	--		--	--		--	--
58	do	do	*k*	Gypsum [5]	do	1	30	18	--	--	--	--	--	--	--	--		45	--	--		--	--		--	--
59	do	do	*k*	do [6]	do	1	30	20	--	--	--	--	--	--	--	--		44	--	--		--	--		--	--
60	8-O-S	8 by 10½	*p-1*	None	do	4	25	13	*3*	*03*	3	38	*3*	*10*	3	46		190	--	--		--	--		1	22
61	8-K-S	4 by 4	*o-1*	do	do	3	21	20	2	49	3	19	--	--	--	--	190	142	4	20	245	4	00	160	0	57
62	8-L-S	do	*k-1*	do	do	2	22	18	1	48	2	19	--	--	--	--	220	147	3	20	289	3	00	182	1	15
63	do	do	*k-3*	do	do	1	38	29	1	49	2	01	--	--	--	--	109	94	2	50	225	2	30	160	1	10
64	8-U-S	do	*k-2*	do	do	2	42	26	2	49	--	--	--	--	--	--	128	87	4	05	218	4	00	135	1	18
65	8-O-S	do	*r*	do	do	6	00	20	*2*	*02*	2	25	--	--	--	--		282	--	--		--	--		0	58
66	do	do	*r*	do	do	0	45	26	--	--	--	--	--	--	--	--		30	--	--		--	--		--	--

[1] All plaster 1:3 volume parts calcined gypsum, Portland cement, or hydrated lime, and sand, applied in two body coats, unless otherwise indicated.

[2] Repaired by filling the exposed-side cells. The temperatures are not given here, as the walls were not aged long enough to allow the excess water in the exposed-side cells to be driven off. This water retarded the temperature rise much more than might be expected with a well-seasoned repaired wall.

[3] Two coats 1:3 plaster plus finish coat of 1:1 lime putty and calcined gypsum.

[4] One coat.

[5] One coat 1:3 plaster plus finish coat of plastic gypsum.

[6] Two coats 1:3 plaster plus finish coat of plastic gypsum.

TABLE 17.—*Temperature data from fire-endurance tests*—Continued

8-INCH WALLS OF FIRE-CLAY TILE

No.	Wall: Type	Wall: Size (feet)	Source	Plaster: Exposed side	Plaster: Unexposed side	Test duration	Initial room temperature	Time of 138.9° C. average rise: Under pad	Time of 138.9° C. average rise: On free surface	Time of 180.6° C. maximum rise: Under pad	Time of 180.6° C. maximum rise: On free surface	Temperature rise at end of test: Under pad	Temperature rise at end of test: On free surface	Average temperature rise after test: Under pad: Time	Average temperature rise after test: Under pad: Temperature	Average temperature rise after test: On free surface: Time	Average temperature rise after test: On free surface: Temperature	Time of 200° C. rise 4 inches from unexposed surface
						H. m.	°*C.*	*H. m.*	*H. m.*	*H. m.*	*H. m.*	°*C.*	°*C.*	*H. m.*	°*C.*	*H. m.*	°*C.*	*H. m.*
67	8-A-E	16 by 11	*n*	None	None	6 00	7	*2 23*	2 50	*2 36*	3 06		246	-- --		-- --		1 20
68	do	do	*n*	Gypsum	Gypsum	6 00	12	*4 35*	5 27	*5 02*	6 00		156	-- --		7 30	180	2 18
69	do	8 by 10½	*n*	None	None	6 00	1	*2 23*	2 50	*2 17*	2 43		287	-- --		-- --		1 23
70	do	do	*n*	Gypsum	Gypsum	6 00	1	*4 37*	5 30	*4 50*	5 45		166	-- --		6 45	184	2 30
71	do	8 by 11	*n*	None	None	4 40	13	2 02	2 20	*2 05*	2 29	388	265	5 00	410	5 00	266	1 14
72	do	do	*n*	Gypsum	Gypsum	4 40	13	4 28	5 35	-- --	-- --	157	110	6 15	258	6 15	152	2 26
73	do	4 by 4	*l*	None	None	6 00	29	*1 27*	1 43	-- --	-- --		322	-- --		-- --		0 52
73a	do	do	*l*	do	do	1 26	12	1 25	1 25	-- --	-- --	143	144	2 20	254	2 05	200	1 01
74	do	8 by 10½	*l*	do	do	3 01	17	*1 31*	1 48	*1 37*	1 55		250	-- --		3 25	261	1 14
75	do	do	*l*	do	do	3 01	17	*1 43*	2 03	*1 50*	2 11		232	-- --		3 25	243	1 08
76	do	16 by 11	*l*	do	do	6 00	14	*1 52*	2 13	*2 08*	2 27		341	-- --		6 10	343	1 07
77	do	8 by 11	*l*	Gypsum	do	5 42	13	*2 46*	3 18	*2 41*	3 12		239	-- --		6 10	250	2 00
78	do	do	*l*	Cement 1:3 plus 15 per cent lime.	do	5 42	13	*2 46*	3 18	*2 41*	3 12		239	-- --		6 10	250	2 00
79	8-A-S	8 by 10½	*l*	None	do	2 00	4	*1 30*	1 47	*1 32*	1 50		178	-- --		2 30	223	1 05
80	do	do	*l*	Gypsum	Gypsum	2 00	4	-- --	-- --	-- --	-- --		65	-- --		4 00	84	2 05
81	do	8 by 11	*l*	None	None	4 10	−1	*1 30*	1 47	*1 20*	1 35		332	-- --		4 30	338	0 58
82	do	do	*l*	Gypsum	Gypsum	4 10	−1	*3 17*	3 55	*3 40*	4 22		160	-- --		5 00	197	1 38
83	8-B-E	4 by 4	*m*	None	None	1 30	23	*1 16*	1 31	-- --	-- --		136	-- --		-- --		1 06
84	do	do	*m*	Gypsum [3]	Gypsum [3]	1 30	31	-- --	-- --	-- --	-- --		53	-- --		-- --		1 32
85	do	8 by 11	*m*	Cement 1:3 plus 15 per cent lime.	None	6 00	−3	*1 51*	2 12	*1 44*	2 04		313	-- --		6 10	314	1 24
86	do	do	*m*	Gypsum	Gypsum	6 00	−3	*3 12*	3 48	*3 32*	4 12		228	-- --		6 30	235	1 38
87	do	do	*m*	do	do	3 30	12	*3 52*	-- --	-- --	-- --	105	83	5 30	215	5 30	127	2 20
88	8-BI-E	do	*m*	do	None	3 30	12	*3 42*	-- --	-- --	-- --	121	85	5 10	196	5 15	133	-- --
89	8-D-E	do	*m*	None	do	6 00	21	*1 59*	2 22	*2 06*	2 30		279	-- --		-- --		1 06
90	do	do	*m*	Gypsum	Gypsum	6 00	21	*4 14*	5 02	*4 14*	5 02		175	-- --		7 00	206	2 04
91	8-E-E	4 by 4	*m*	None	None	6 00	16	*1 59*	2 22	-- --	-- --		250	-- --		-- --		0 42
92	do	do	*m*	do	do	1 05	18	-- --	-- --	-- --	-- --		31	-- --		-- --		0 49
93	do	do	*m*	do	do	6 00	21	*1 52*	2 13	-- --	-- --		272	-- --		-- --		0 42
94	do	do	*n*	do	do	3 42	23	3 13	3 31	-- --	-- --	205	144	3 45	274	3 30	170	0 51
95	do	do	*m*	Gypsum	Gypsum	4 07	3	*3 54*	3 16	*3 10*	3 35		246	-- --		-- --		-- --
97	8-L-S	do	*m*	None	do	6 00	22	*3 20*	3 58	*3 33*	4 12		224	-- --		4 20	248	

97	8-L-S	do	m	Gypsum	Gypsum	6	00	22	3	20	3	58	3	33	4	13		224	--	--		6	30	231	--	--
97	8-L-S	do	m	None	None	4	07	3	1	32	1	49	1	31	1	48		274	--	--		4	05	274	--	--
98	do	do	m	Gypsum	Gypsum	6	00	22	2	40	3	10	2	23	2	50		259	--	--		6	25	263	1	40
99	8-K-S	4 by 4	l-2	None	None	2	11	20	2	08	2	22	--	--	--	--	146	116	3	40	260	3	00	173	0	55
101	8-O-S	do	l-1	do	do	6	00	20	2	09	2	34	--	--	--	--		278	--	--		--	--		1	00
102	do	do	l-1	do	do	1	30	25	--	--	--	--	--	--	--	--		57	--	--		--	--		0	54
103	8-P-S	do	l	do	do	6	00	18	1	45	2	05	--	--	--	--		299	--	--		--	--		0	43
104	do	do	l	do	do	1	30	18	--	--	--	--	--	--	--	--		61	--	--		--	--		0	49
105	do	8 by 11	l	do	do	6	00	−3	2	26	2	54	2	31	3	00		260	--	--		6	25	267	1	02
106	do	do	l	Gypsum	Gypsum	6	00	−3	4	52	5	48	--	--	--	--		149	--	--		7	10	167	--	--
107	8-Q-S	4 by 4	f	None	None	3	23	11	1	49	2	10	1	56	2	18		248	--	--		3	50	262	0	49
108	do	do	f	Gypsum	Gypsum	4	53	16	3	33	4	33	--	--	--	--	256	157	6	10	318	6	00	186	--	--
109	8-Q-E	do	f	do	do	4	45	10	3	35	4	33	--	--	--	--	267	153	6	00	329	5	50	195	--	--
110	10-H-S	8 by 10½	l	do	Cement 1:3 plus 15 per cent lime.	4	02	11	4	07	--	--	--	--	--	--	132	94	5	45	211	5	30	130	1	12
111	10-N-S	do	l	do	do	4	02	11	4	06	--	--	--	--	--	--	134	85	5	45	221	--	--		1	20
112	8-MZ-S	do	m	do	Brick	5	31	8	4	56	5	52	--	--	--	--		119	--	--		7	00	153	2	26
113	8-JZ-E	do	m	do	do	5	31	8	4	33	5	25	--	--	--	--		141	--	--		7	00	164	2	01

12-INCH WALLS OF SHALE TILE

114	12-A-E	4 by 4	d	None	None	6	00	28	2	56	3	30	--	--	--	--		229	--	--		--	--		2	42
115	do	do	d	do	do	3	00	22	3	02	3	37	--	--	--	--		99	--	--		4	25	164	2	38
116	12-AH-E	do	d	do	do	6	00	28	3	51	4	35	--	--	--	--		203	--	--		--	--		3	40
117	do	do	d	do	do	3	00	26	--	--	--	--	--	--	--	--		67	--	--		4	45	116	--	--
118	12-O-S	8 by 10½	d-1	do	do	5	00	5	--	--	--	--	--	--	--	--		58	--	--		8	50	109	4	25

12-INCH WALLS OF SURFACE-CLAY TILE

119	12-C-E	4 by 4	j	None	None	4	10	16	--	--	--	--	--	--	--	--		101	--	--		--	--		4	00
120	12-CH-E	do	j	do	do	5	23	23	--	--	--	--	5	22	--	--	97	80	--	--		6	30	102	4	05
121	do	do	j	do	do	6	00	12	--	--	--	--	--	--	--	--		111	--	--		7	05	130	5	24
122	do	do	j	do	do	3	00	16	--	--	--	--	--	--	--	--		36	--	--		--	--		--	--
123	do	8 by 10½	j	do	do	2	22	16	--	--	--	--	--	--	--	--		41	--	--		5	30	68	2	24
124	12-BJ-E	do	k	do	do	5	00	23	5	01	--	--	--	--	--	--	137	89	7	00	199	7	00	136	2	21
125	12-O-S	4 by 4	p-1	do	do	8	33	27	8	32	--	--	--	--	--	--	142	98	11	15	219	10	20	154	5	54
125a	do	do	p-1	do	do	5	43	16	5	40	--	--	--	--	--	--	142	87	7	45	204	7	30	127	3	40
126	do	do	p-1	Gypsum	Gypsum	10	42	25	10	43	--	--	--	--	--	--	137	96	13	30	234	13	00	143	6	30
127	do	8 by 10½	p-1	None	None	5	00	5	--	--	--	--	--	--	--	--	72	63	8	40	174	8	40	113	4	35
128	do	do	p-1	do	do	6	00	22	--	--	--	--	--	--	--	--		70	--	--		8	45	119	--	--
129	do	do	p-1	Gypsum	Gypsum	6	00	22	--	--	--	--	--	--	--	--		41	--	--		10	00	70	--	--

[a] Two coats 1:3 plaster plus finish coat of 1:1 lime putty and calcined gypsum.

TABLE 17.—*Temperature data from fire-endurance tests*—Continued

12-INCH WALLS OF FIRE-CLAY TILE

No.	Wall: Type	Wall: Size (feet)	Source	Plaster: Exposed side	Plaster: Unexposed side	Test duration	Initial room temperature	Time of 138.9° C. average rise: Under pad	Time of 138.9° C. average rise: On free surface	Time of 180.6° C. maximum rise: Under pad	Time of 180.6° C. maximum rise: On free surface	Temperature rise at end of test: Under pad	Temperature rise at end of test: On free surface	Average temperature rise after test: Under pad: Time	Average temperature rise after test: Under pad: Temperature	Average temperature rise after test: On free surface: Time	Average temperature rise after test: On free surface: Temperature	Time of 200° C. rise 4 inches from unexposed surface
						H. m.	*° C.*	*H. m.*	*H. m.*	*H. m.*	*H. m.*	*° C.*	*° C.*	*H. m.*	*° C.*	*H. m.*	*° C.*	*H. m.*
130	12-A-E	4 by 4	*l*	None	None	6 00	22	*2 45*	3 16	-- --	-- --	------	254	-- --	------	-- --	------	2 24
131	do	do	*l*	do	do	3 00	23	*3 01*	3 36	-- --	-- --	------	96	-- --	------	4 25	157	2 45
132	do	16 by 11	*l*	do	do	6 00	22	-- --	-- --	-- --	-- --	------	215	-- --	------	6 30	220	2 41
133	12-AH-E	4 by 4	*l*	do	do	6 00	15	*4 03*	4 49	-- --	-- --	------	178	-- --	------	-- --	------	4 36
133a	do	do	*l*	do	do	3 38	18	3 36	-- --	-- --	-- --	141	116	5 00	219	4 50	171	3 02
134	do	do	*l*	do	do	3 00	26	-- --	-- --	-- --	-- --	------	71	-- --	------	-- --	------	-- --
135	12-G-E	8 by 11	*n*	do	do	6 00	6	*4 09*	4 57	*3 17*	3 55	------	175	-- --	------	7 00	186	3 00
136	do	do	*n*	Gypsum	Gypsum	6 00	6	6 00+	-- --	-- --	-- --	------	57	-- --	------	9 00	93	5 00
137	12-P-S	4 by 4	*l*	None	None	5 05	25	5 05	-- --	-- --	-- --	139	87	6 45	193	6 30	135	2 46
138	do	do	*l*	Gypsum	Gypsum	8 34	23	8 37	-- --	-- --	-- --	136	82	11 15	212	11 00	140	5 25
139	12-Q-S	do	*f*	None	None	5 32	17	4 32	5 12	-- --	-- --	216	156	7 00	279	6 55	186	2 40
140	do	do	*f*	Gypsum	Gypsum	8 15	19	6 39	8 09	-- --	-- --	224	143	10 00	281	9 50	176	3 40
141	12-VXZ-E	do	*p*	None	Brick	4 00	19	-- --	-- --	-- --	-- --	58	50	11 00	90	11 00	59	-- --
142	do	do	*p*	Gypsum	do	4 00	12	-- --	-- --	-- --	-- --	37	32	9 45	53	9 45	45	-- --
143	do	do	*p*	Brick	None	4 00	16	-- --	-- --	-- --	-- --	49	45	-- --	------	-- --	------	-- --
144	do	do	*p*	Gypsum	Brick	2 00	15	-- --	-- --	-- --	-- --	11	9	-- --	------	-- --	------	-- --
145	12-WY-E	do	*p*	do	None	1 00	18	-- --	-- --	-- --	-- --	0	0	-- --	------	-- --	------	-- --
146	12-LMZ-S	8 by 10½	*m*	do	Brick	6 00	19	6 00+	-- --	-- --	-- --	------	68	-- --	------	9 00	124	3 32
147	12-VXZ-E	do	*m*	do	do	6 00	19	6 00+	-- --	-- --	-- --	------	68	-- --	------	8 35	136	3 08

16-INCH WALL OF SHALE TILE

148	16-AH-E	16 by 11	*d*	None	None	5 11	3	-- --	-- --	*4 11*	4 59	------	102	-- --	------	-- --	------	4 38

16-INCH WALLS OF SURFACE CLAY TILE

| | | |

The times required to obtain an average temperature rise of 139° C. (250° F.), as measured by the unprotected couples (*S*) and as measured by the couple under the pad (*P*), are given in Table 17. When the pads were not used the time required for the 139° C. (250° F.) temperature rise under the pad was calculated from the average relation obtained from the tests where both methods were used, the calculated periods being indicated by italics in the table. The time at which a maximum temperature rise of 180.6° C. (325° F.)[26] obtained at any couple location is also recorded in Table 17 for the large walls. For the small walls the size was not large enough to develop a representative variation, and hence generally only the average temperature is reported. This high point of the average temperature rise after the fire was shut off and the time from the start of the test required to reach it are also given in this table.

(e) TEST DURATION

The fire exposure in the earlier tests was continued for 1 hour and 30 minutes or for 6 hours, unless failure of the wall under load occurred sooner. The exposure in the later tests was generally terminated when an average temperature rise of 139° C. (250 ° F.) was obtained on the unexposed surface as measured by the couples (*P*) under the small pads. A few tests were continued for 1, 2, 3, or 4 hours to determine the effects on the tile of fire of these durations. Some tests were stopped before the 139° C. (250 ° F.) temperature rise was obtained, to determine the length of time the wall could be exposed to fire without causing unduly high temperatures on the unexposed surface after the fire was shut off.

(f) EXPANSION

A measure of the vertical expansion of the small walls tested under load was obtained by measuring the movement of the head of the frame by means of a cathetometer on a fixed target mounted on the center of the top of the head of the frame. Typical curves are given in Figure 19a. The measurement as made was subject to error from the expansion of the head and bottom pieces of the frame. After a given period of fire exposure the expansion for most of the walls attained a maximum, due apparently to yielding or shrinkage of mortar in the horizontal joints. In tests of long duration the tile apparently also softened sufficiently to make the yielding under the applied load greater than the thermal expansion.

(g) LATERAL DEFLECTION

The lateral deflections of the restrained and loaded walls were toward the fire during the test. After cooling, the deflections of some of these walls were away from the fire. The deflections at

[26] Appendix C, p. 330.

the top of the unrestrained walls were away from the fire both during test and after cooling. The maximum deflections as measured at the center of the large restrained and loaded walls and at the top (average of corners and center) of the unrestrained walls, during the

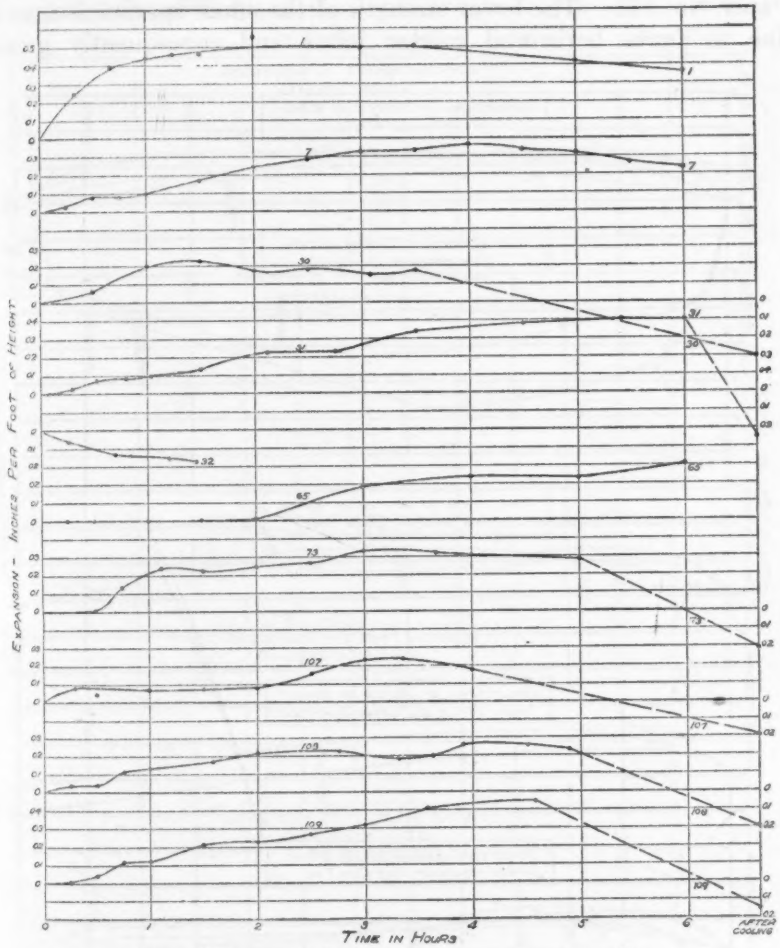


FIG. 19a.—*Typical expansion curves of small walls*

test and after the wall had cooled, are given in Table 16. Typical deflection curves are given in Figures 19b and 19c.

(h) COMPRESSION TESTS OF MASONRY SPECIMENS

The compressive strength of masonry specimens built simultaneously with the large walls and of specimens of similar size cut from the large walls after they had been subjected to the fire exposure are given in Table 11. Tiles from some of these sources were included in a series of compression tests of large walls and reported in a previous paper.[27]

[27] B. S. Tech. Paper No. 311.

Comparison of 10 average values obtained from comparable tests in the two series gives a compressive strength for the small wall sections tested in connection with the fire tests 18.2 per cent lower than the average reported for similar large walls in Technologic Paper No. 311. The lower strength of the small specimens may be due to fewer horizontal mortar joints and consequently greater

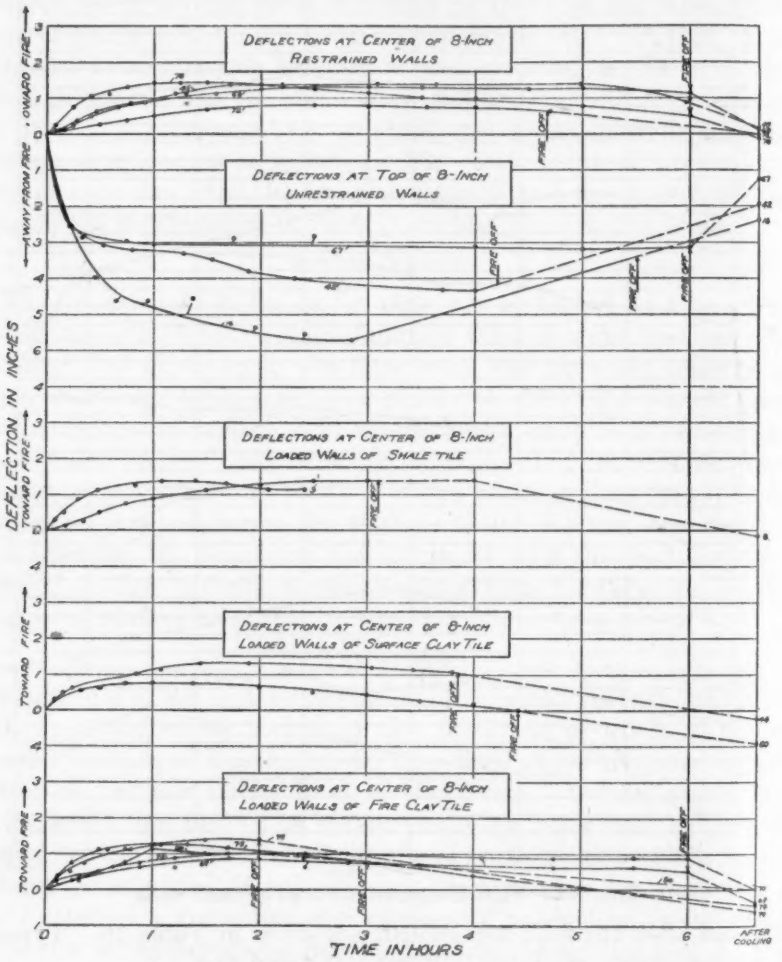

DEFLECTIONS AT CENTER OF 8-INCH RESTRAINED WALLS
DEFLECTIONS AT TOP OF 8-INCH UNRESTRAINED WALLS
DEFLECTIONS AT CENTER OF 8-INCH LOADED WALLS OF SHALE TILE
DEFLECTIONS AT CENTER OF 8-INCH LOADED WALLS OF SURFACE CLAY TILE
DEFLECTIONS AT CENTER OF 8-INCH LOADED WALLS OF FIRE CLAY TILE
DEFLECTION IN INCHES
AWAY FROM FIRE
TOWARD FIRE
FIRE OFF
AFTER COOLING
TIME IN HOURS

FIG. 19b.—*Typical deflection curves of large walls*

possibility of stress concentrations from uneven mortar joints and unequal size of units. However, this would not affect the comparison on strength obtained between masonry specimens of comparable size tested in compression without previous fire exposure, and cut from the walls after fire test.

(i) LOG OF FIRE-ENDURANCE TESTS

The log of the tests includes observations of fire effects on the exposed and unexposed sides, formation of cracks, ability to carry load both during and after test, and general condition of wall and individual units after the test.

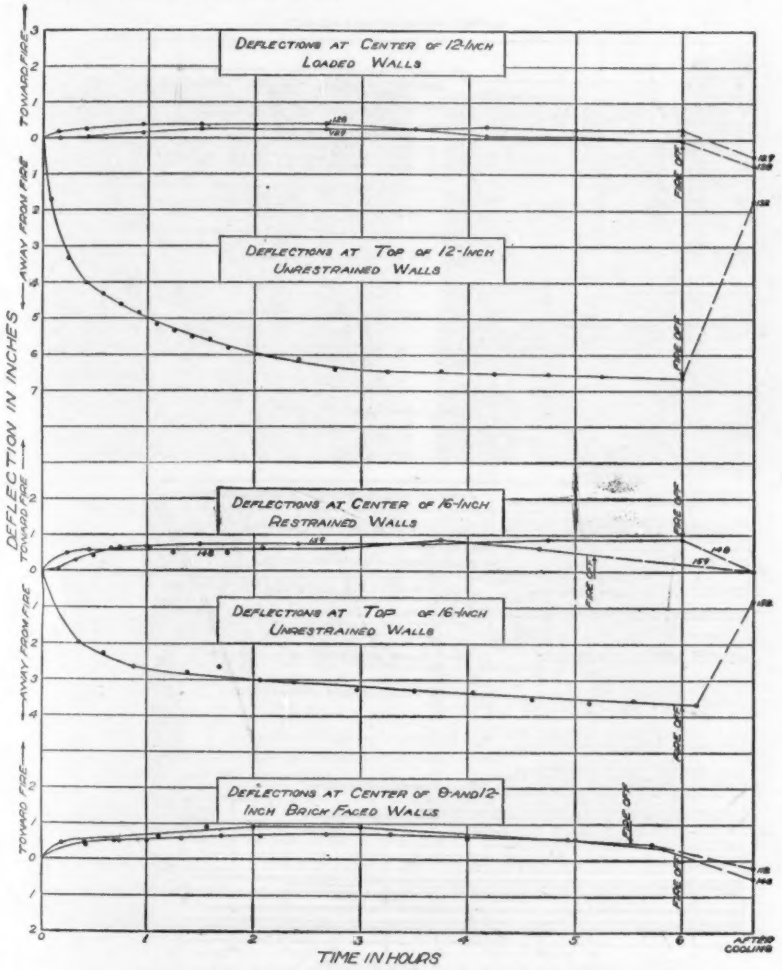

DEFLECTIONS AT CENTER OF 12-INCH LOADED WALLS
DEFLECTIONS AT TOP OF 12-INCH UNRESTRAINED WALLS
DEFLECTIONS AT CENTER OF 16-INCH RESTRAINED WALLS
DEFLECTIONS AT TOP OF 16-INCH UNRESTRAINED WALLS
DEFLECTIONS AT CENTER OF 8- AND 12-INCH BRICK FACED WALLS
DEFLECTION IN INCHES
TOWARD FIRE
AWAY FROM FIRE
FIRE OFF
TIME IN HOURS
AFTER COOLING

FIG. 19c.—*Typical deflection curves of large walls*

In the logs reference is made to sketches illustrating the type of construction, the time-temperature curves, photographs of the wall, or of other walls in similar condition.

TEST No. 1.—4 by 4 ft.; 8-in. wall unplastered 120 lbs./in.^{2} load; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *d* (Type 8-A-E., fig. 12a)—½ to 3 mins.—rapid succession of snapping sounds caused by spalling from exposed surface. 18 mins. to 1 hr. 30 mins.—occasional loud cracking sounds, probably from fracture of webs holding exposed shells. 5 hrs.—tile bulging endwise near center of one edge of wall. 5 hrs. 10 mins.—part of one exposed shell at edge

of wall fell out. 18 mins.—steam coming through poorly filled mortar joints near top. 40 mins.—steam coming through cracks at mid height of wall. 57 mins.—steam coming through cracks in mortar joints near bottom of wall. 2 hrs. 15 mins.—crack in horizontal mortar joint on exposed side started and opened to ⅛ in. by 4 hrs. 20 mins., indicating yielding in tile and mortar joints on fire side. Test ended at 6 hrs., which was 4 hrs. 49 mins. beyond the resistance

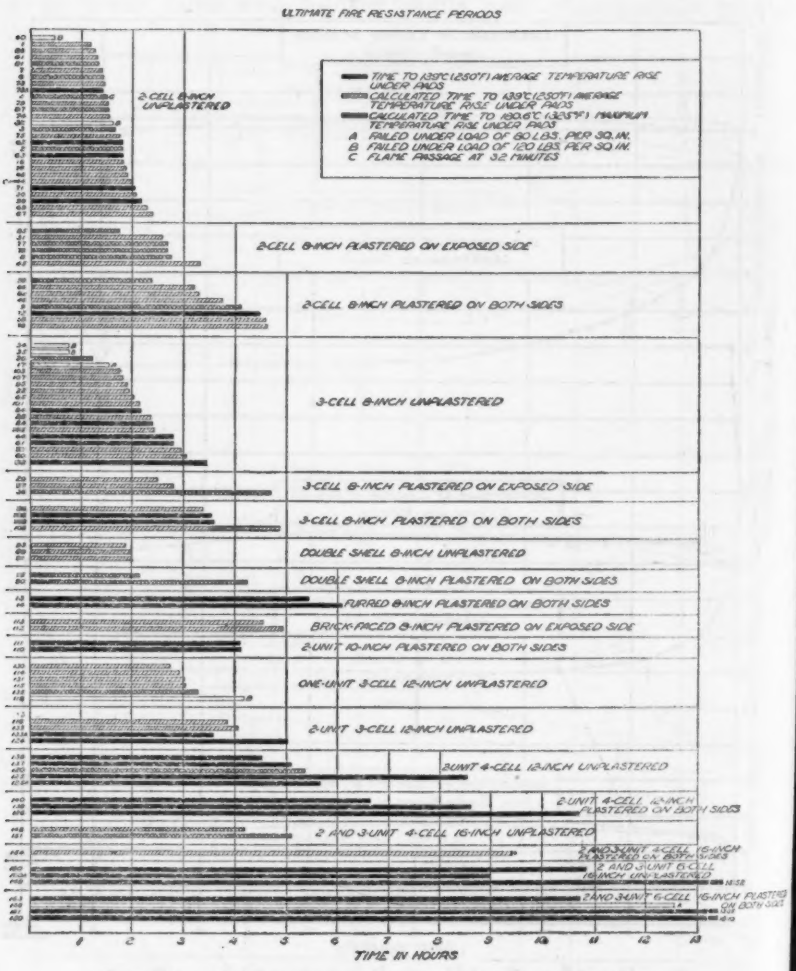

ULTIMATE FIRE RESISTANCE PERIODS
TIME TO 139°C (250°F) AVERAGE TEMPERATURE RISE UNDER PADS
CALCULATED TIME TO 139°C (250°F) AVERAGE TEMPERATURE RISE UNDER PADS
CALCULATED TIME TO 180.6°C (325°F) MAXIMUM TEMPERATURE RISE UNDER PADS
A FAILED UNDER LOAD OF 80 LBS. PER SQ. IN.
B FAILED UNDER LOAD OF 120 LBS. PER SQ. IN.
C FLAME PASSAGE AT 3.2 MINUTES
2-CELL 8-INCH UNPLASTERED
2-CELL 8-INCH PLASTERED ON EXPOSED SIDE
2-CELL 8-INCH PLASTERED ON BOTH SIDES
3-CELL 8-INCH UNPLASTERED
3-CELL 8-INCH PLASTERED ON EXPOSED SIDE
3-CELL 8-INCH PLASTERED ON BOTH SIDES
DOUBLE SHELL 8-INCH UNPLASTERED
DOUBLE SHELL 8-INCH PLASTERED ON BOTH SIDES
FURRED 8-INCH PLASTERED ON BOTH SIDES
BRICK-FACED 8-INCH PLASTERED ON EXPOSED SIDE
2-UNIT 10-INCH PLASTERED ON BOTH SIDES
ONE-UNIT 3-CELL 12-INCH UNPLASTERED
2-UNIT 3-CELL 12-INCH UNPLASTERED
2-UNIT 4-CELL 12-INCH UNPLASTERED
2-UNIT 4-CELL 12-INCH PLASTERED ON BOTH SIDES
2 AND 3-UNIT 4-CELL 16-INCH UNPLASTERED
2 AND 3-UNIT 4-CELL 16-INCH PLASTERED ON BOTH SIDES
2 AND 3-UNIT 6-CELL 16-INCH UNPLASTERED
2 AND 3-UNIT 6-CELL 16-INCH PLASTERED ON BOTH SIDES
TIME IN HOURS

FIG. 20.—*Ultimate fire resistance periods of hollow tile walls*

period of the wall, as determined by the temperature rise on the unexposed surface. Wall carried full load at end of test. (Temperature curves in fig. 56.)

After test.—Half of exposed shells of three tile at one end off. Tile at this end buckled and carrying no load. All of exposed surface glazed from incipient fusion. (Softening temperature of tile 1,180° C., Table 2.) All exposed shells loose and easily pulled off. Webs holding unexposed shells were also cracked so that the shells were loose. (Condition shown in fig. 21.)

TEST No. 2.—8 by 10⅛ ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 inch end-construction shale tile from source *d*. (Type 8-A-E.)

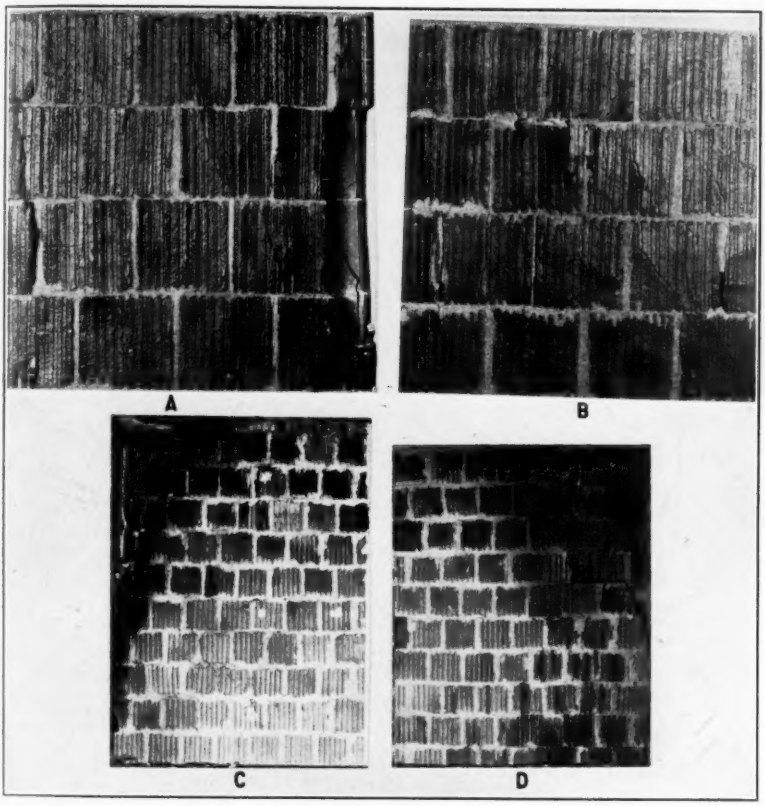


FIG. 21

A, exposed side of wall No. 1 after fire exposure of 6 hours
B, exposed side of wall No. 7 after fire exposure of 6 hours
C, unexposed side of wall No. 3 after fire exposure of 2 hours 51 minutes
D, exposed side of wall No. 3 after fire exposure of 2 hours 51 minutes

UNIV. OF MICH.

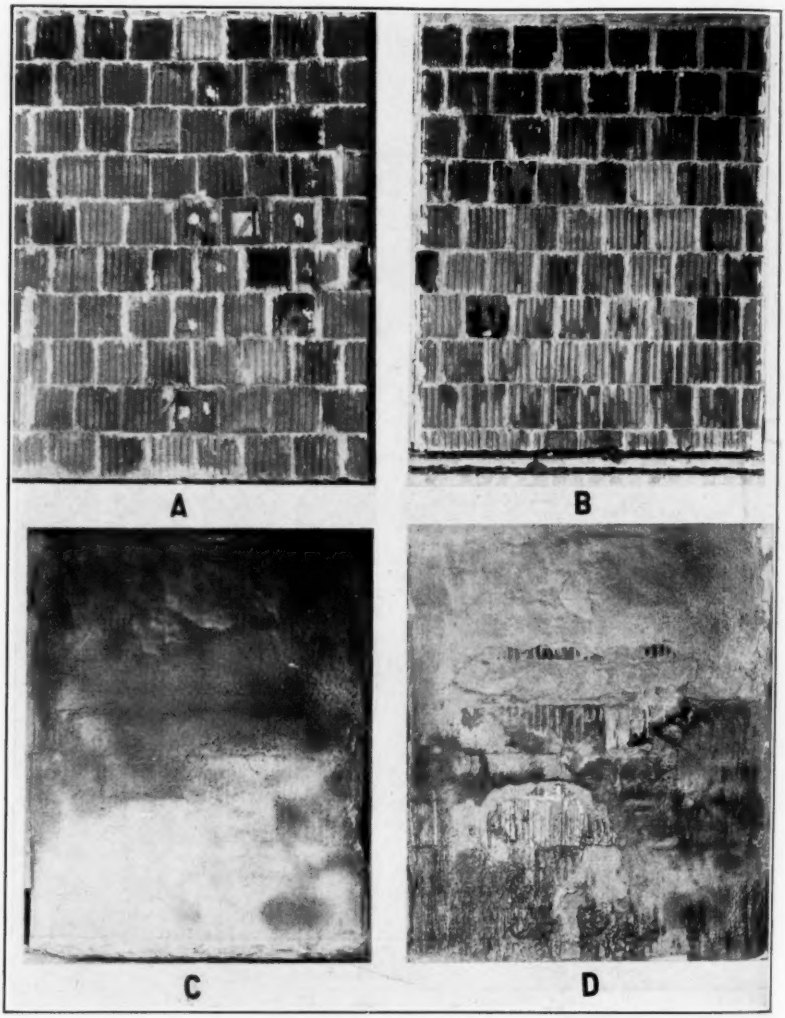


FIG. 22

A, unexposed side of north half of wall No. 4 after fire exposure of 2 hours 17 minutes
B, exposed side of north half of wall No. 4 after fire exposure of 2 hours 17 minutes
C, exposed side of north half of wall No. 5 before fire exposure. (This wall was obtained by repairing wall No. 4)
D, exposed side of north half of wall No. 5 after fire exposure of 5 hours 7 minutes

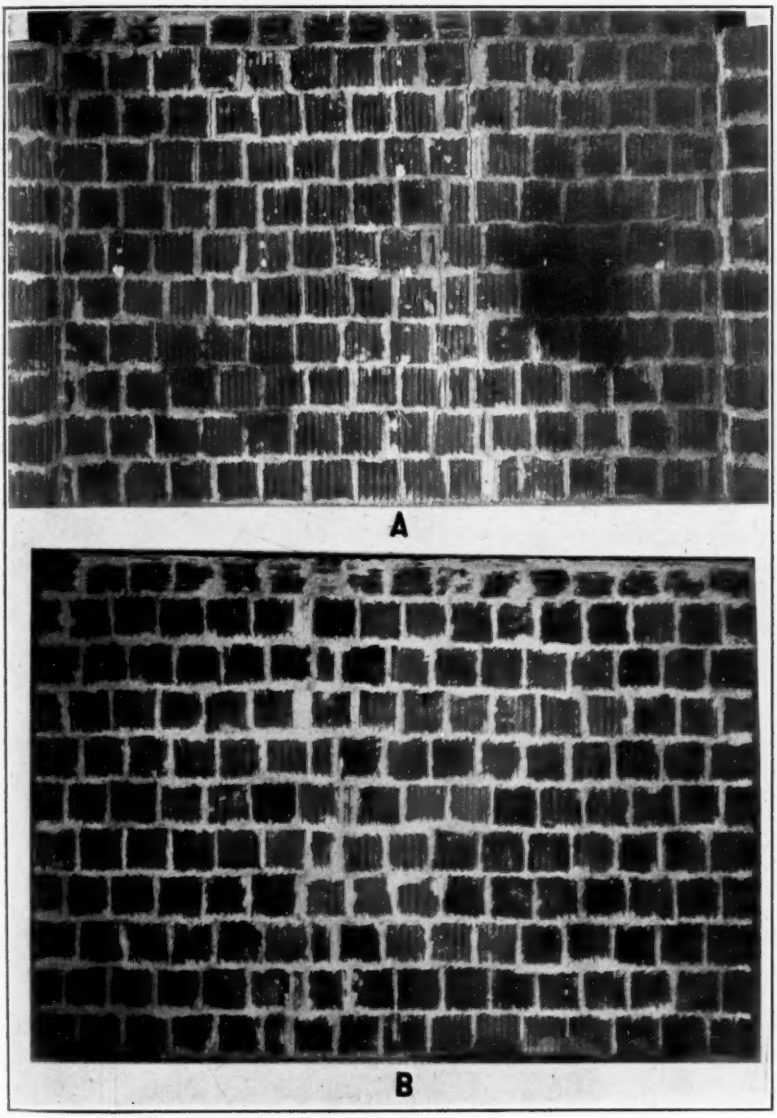


FIG. 23

A, unexposed side of wall No. 6 after fire exposure of 2 hours 53 minutes
B, exposed side of wall No. 6 after fire exposure of hours 53 minutes

UNIV. OF MICH.

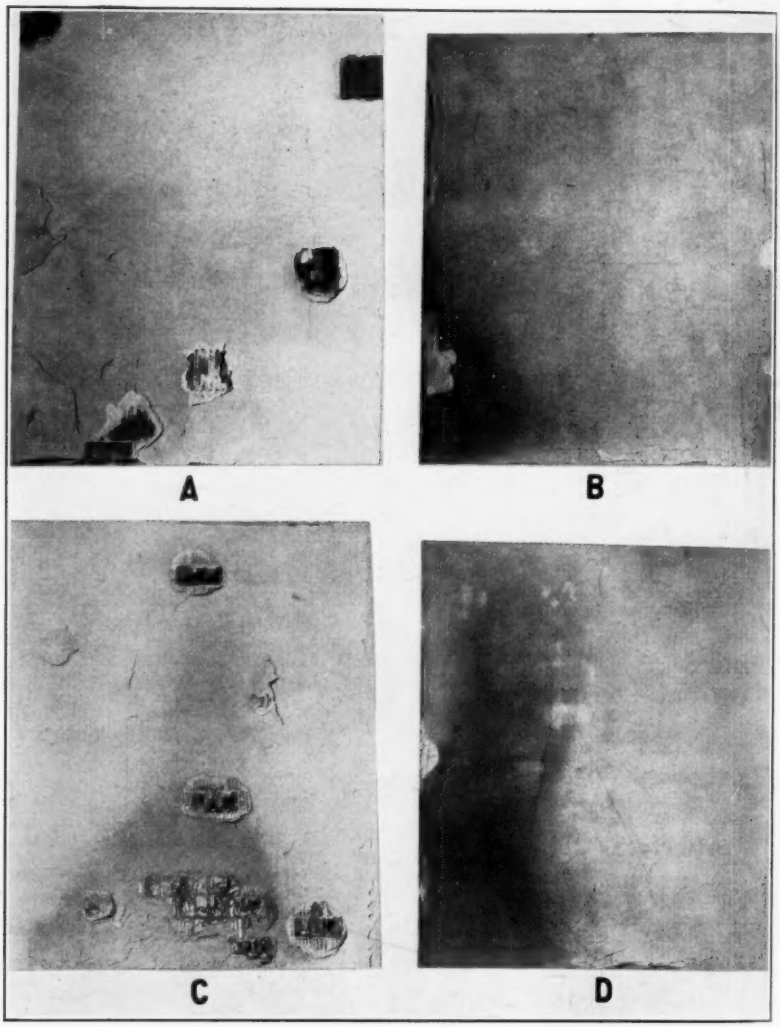


FIG. 24

A, exposed side of wall No. 9 after fire exposure of 5 hours 30 minutes
B, exposed side of wall No. 10 after fire exposure of 5 hours 30 minutes
C, exposed side of wall No. 15 after fire exposure of 5 hours 30 minutes
D, exposed side of wall No. 16 after fire exposure of 5 hours 30 minutes

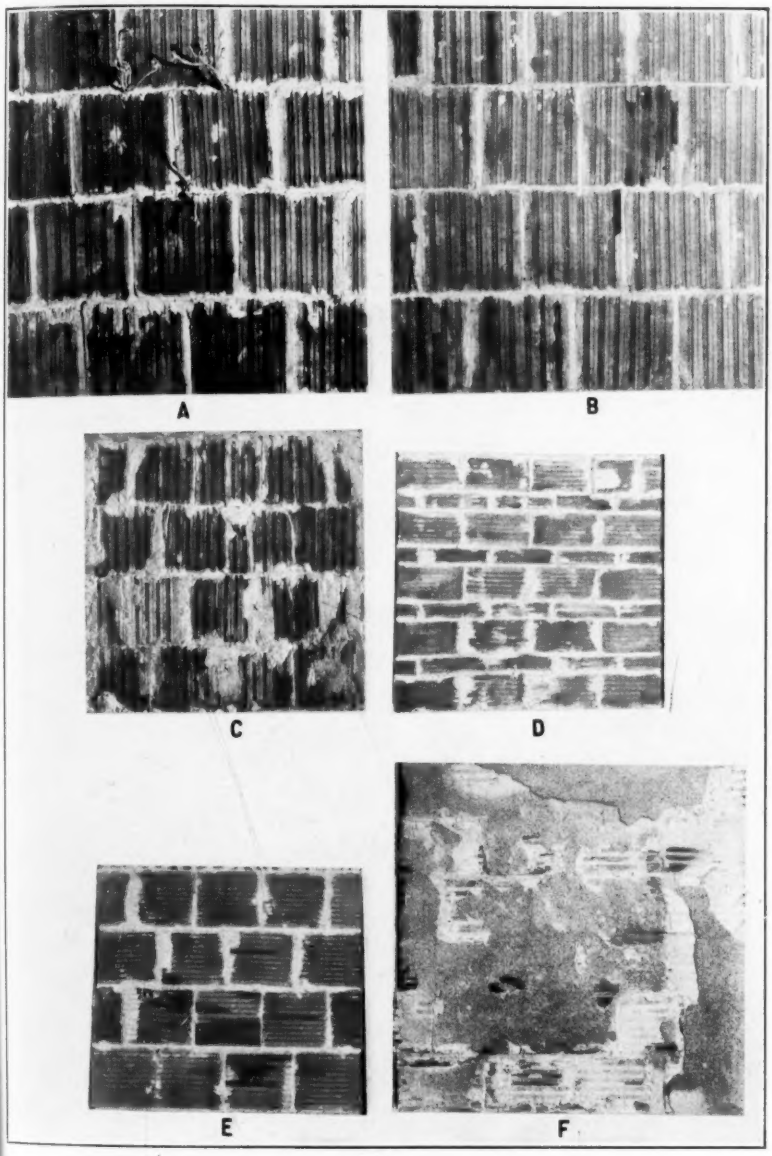


FIG. 25

A, unexposed side of wall No. 11 after fire exposure of 1 hour 30 minutes
B, exposed side of wall No. 11 after fire exposure of 1 hour 30 minutes
C, exposed side of wall No. 14 after fire exposure of 6 hours 6 minutes, and after removing furring
D, exposed side of wall No. 20 after fire exposure of 1 hour 30 minutes
E, exposed side of wall No. 23 after fire exposure of 1 hour 30 minutes
F, exposed side of wall No. 27 after fire exposure of 6 hours

UNIV. OF MICH.

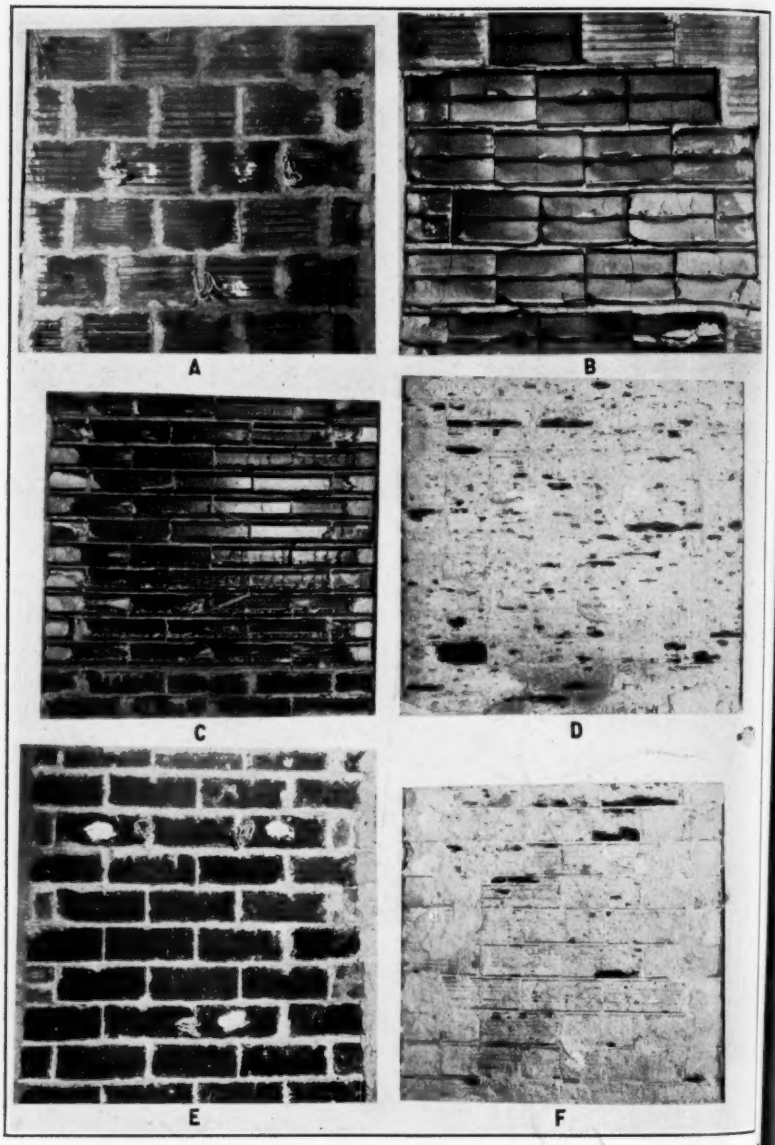


FIG. 26

A, unexposed side of wall No. 26 after fire exposure of 3 hours 12 minutes
B, exposed side of wall No. 26 after fire exposure of 3 hours 12 minutes
C, exposed side of wall No. 28 after fire exposure of 3 hours 56 minutes
D, exposed side of wall No. 29 after fire exposure of 4 hours 43 minutes
E, unexposed side of wall No. 30 after fire exposure of 3 hours 36 minutes
F, exposed side of wall No. 30 after fire exposure of 3 hours 36 minutes

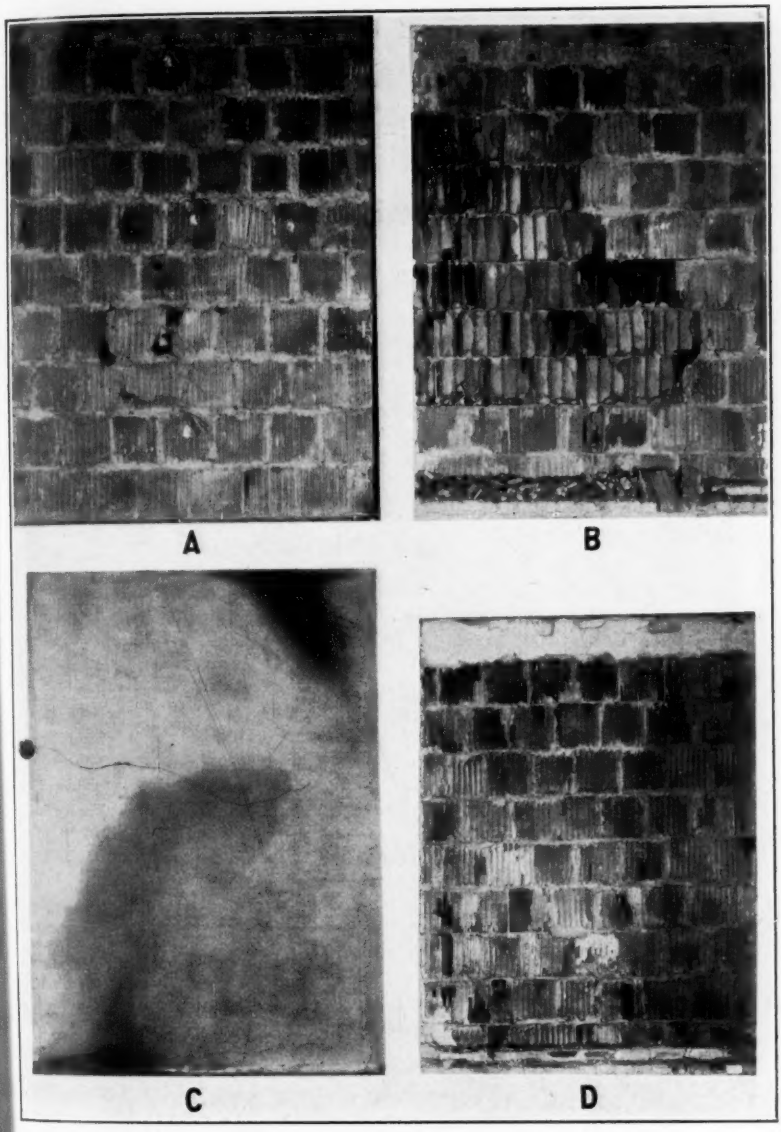


FIG. 27

A, unexposed side of wall No. 35 after fire exposure of 45 minutes
B, exposed side of wall No. 35 after fire exposure of 45 minutes
C, exposed side of wall No. 36 after fire exposure of 6 hours
D, exposed side of wall No. 38 after fire exposure of 3 hours 31 minutes

UNIV OF MICH

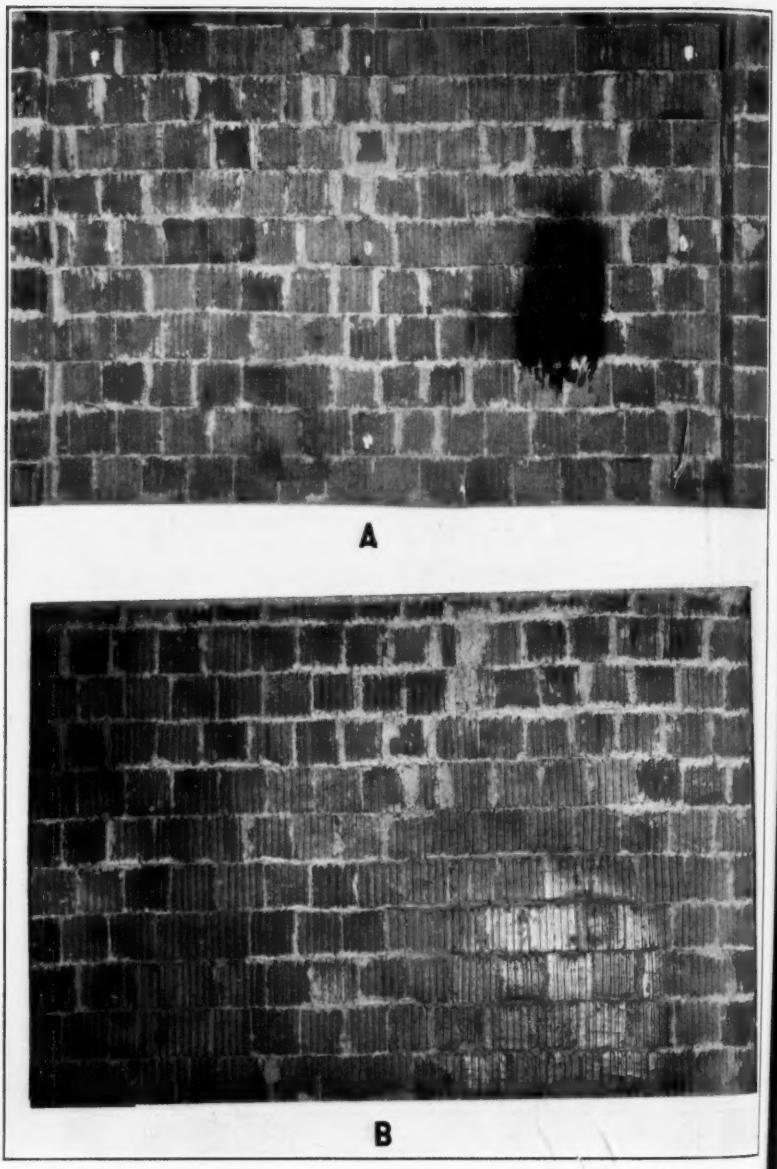


FIG. 28

A, unexposed side of wall No. 42 after fire exposure of 4 hours 12 minutes
B, exposed side of wall No. 42 after fire exposure of 4 hours 12 minutes

fig. 12a.)—½ min.—snapping started. 1 to 12 mins.—succession of snapping sounds. 25 mins.—spalls to depth of scoring on exposed side, mostly on lower portion of wall. 5 mins.—diagonal crack across lower corner. 30 mins.—exposed shells near south end of wall loose. 37 mins.—section of wall 6 in. wide and 4 ft. long in top south corner failing under the load but has not fallen out. 45 mins.—additional tile in top corner failing. 1 hr.—none of the exposed shells off, but several in lower portion of wall loose and bulging. 1 hr. 10 mins.—vertical crack 18 in. from south end of wall extending from top to bottom of wall along vertical mortar joints and across units of alternate courses. 1 hr. 20 mins.—exposed shells of two units in lower south corner fell off. 20 mins. to 1 hr. 50 mins.—steaming and condensation at unexposed side mortar joints. 1 hr. 54 mins.—additional material from top south corner fell out; opening at top corner now about 6 in. wide and 5 ft. long. 2 hrs.—snapping sounds from flaking on unexposed side caused by flame passage around end of wall. 2 hrs. 37 mins.—unexposed shells of two upper courses of south end buckled outward about ½ in. 2 hrs. 40 mins.—excelsior pad taken off. 2 hrs. 51 mins.—wall seems to be near failure under load. Test ended at 2 hrs. 51 mins., which was 1 hr. 3 mins. beyond the resistance period of the wall, as determined by temperature rise on the unexposed surface. (Temperature curves in fig. 57.)

After cooling.—No load applied. Several tile at top south corner of wall had fallen out during the test and during the cooling of the wall. Exposed shells near this opening fused from heat from secondary burners. Exposed shells of south 3 ft. of wall off. Remainder of exposed shells in place but loose. In addition, a few of the tile in the lower portion of the wall and all of those in the upper portion were cracked so that the unexposed shells were also loose. Masonry specimens were not taken from this wall for compression tests. (Condition similar to wall 3, shown in fig. 21.)

Test No. 3.—8 by 10⅓ ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *d* set in cement mortar. (Type 8–A–E, fig. 12a.)—½ min.—snapping sounds. 1 to 12 mins.—succession of snapping sounds. 25 mins.—spalls to depth of scoring on exposed side, mostly on lower portion of wall. 8 to 15 mins.—several vertical cracks from 2 to 3 ft. from north end on unexposed side, extending from top to bottom of wall, generally along vertical mortar joints and across the units of alternate courses. 1 hr. 15 mins.—further formation of vertical cracks on unexposed surface about 3½ ft. from north end. 34 mins.—north 6 in. of upper four courses of tile failed and fell out. Furnace was partly shut off for about 10 mins. so that protection could be provided for thermocouple leads which were opposite this open place. 44 mins.—additional material fell from top north corner. 20 mins. to 1 hr. 50 mins.—steaming and condensation at unexposed side mortar joints. 1 hr. 37 mins.—snapping caused by spalling of small particles from unexposed surface chiefly from flame passage around end of wall. This was continuous to end of test. 2 hrs. 35 mins.—the unexposed shells of the end tile in the upper two courses bulged outward, showing that no load was being taken by the 2 ft. of wall on north end. 2 hrs. 27 mins.—cotton pad removed. 2 hrs. 51 mins.—wall near failure from load. Test was ended at 2 hrs. 51 mins., which was 1 hr. 12 mins. beyond the resistance period of the wall, as determined by temperature rise on the unexposed surface.

After cooling.—No load applied. Top north corner of wall had fallen out during the test and during the cooling of the wall. Parts of tile on exposed side near this corner fused, indicating unusually intense exposure at this point. Exposed shells of upper four courses of tile 3 ft. from north end off. Remainder of shells in place but flaked, especially in lower portion of wall. These shells

were also loose, and, in addition, about 40 per cent of the units were cracked so that the unexposed shells could also be pulled off. Masonry specimens for compression tests were not taken from this wall. (Condition shown in fig. 21.)

TEST No. 4.—16 by 10⅓ ft.; 8 in. wall unplastered; 80 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *d*. (Type 8–A–E, fig. 12a.)—(This wall was divided into two sections each 8 ft. long, but as both sections were alike, the whole is considered as one wall.) 1 min.—many snapping sounds. 5 mins.—spalling of ridges on exposed surface began. 11 mins.—about 50 per cent of ridges in lower three courses spalled. 16 mins.—believe north-end shell of fourth course loose. 20 to 23 mins.—exposed shells of two hard tile near middle of wall in fourth and fifth courses off; flaking of these two tile continued. 32 mins.—flaking of one hard tile now penetrated to unexposed side, allowing passage of flame; exposed shells of other hard tiles flaked decidedly.—50 mins. to 1 hr. 30 mins.—fine cracks following mortar joints in lower corners of wall. 7 mins. to 1 hr. 2 mins.—steam from unexposed mortar joints. 2 hrs. 17 mins.—fire shut off; limiting temperature rise obtained on the unexposed surface at 1 hr. 30 mins. Load increased to 120 lbs./in.²; a little snapping heard in applying the additional load. 2 hrs. 30 mins.—smoke coming from excelsior pad on south portion of wall; pad removed, uncharred; smoke came from resin from pine board of pad. 2 hrs. 50 mins.—smoke coming from excelsior pad on north portion of wall; pad was removed; the parts in contact with wall were charred seriously. (Temperature curves in fig. 58.)

After cooling.—Wall was reloaded. Considerable snapping in applying 80-lb. load. Not much snapping between 80 and 100 lbs.; more in loading to 120 lbs. Approach of ultimate strength of wall indicated. No serious fire effects were noted on the unexposed surface of the wall, except on two very hard tiles through which holes had been formed by spalling. None of the exposed shells were loose, but about 25 per cent of the surface was spalled to depth of scoring; spalling most prominent on hard tile. This wall was not dismantled but repaired for a second test. (Condition shown in fig. 22.)

TEST No. 5.—16 by 10⅓ ft.; wall 4 retested as No. 5, repaired by removing exposed shells of every fourth course and filling the exposed-side cells and covering the surface with "gunite"; 80 lbs./in.² load. 4 to 5 mins.—loud popping and cracking sounds. 10 mins.—large amount of material (gunite) spalled off; spalling to depth of 2 in. 25 mins.—popping and spalling continuing. 40 mins.—nearly all of exposed surface material (gunite) spalled in lower part of wall to tile surface. 50 mins.—no further spalling. 40 mins.—steaming and condensation at mortar joints at top of unexposed surface of wall. 1 hr.—so much steam from wall that enough water condensed to run off bottom of wall in small streams; this due to wet filling used in repairing and to short aging period. 3 hrs. 30 mins.—opening of horizontal mortar joints on unexposed side, indicating loosened shells and yielding on fire side. 5 hrs. 7 mins.—fire shut off; load increased to 120 lbs./in.² without noticeable effects. 5 hrs. 10 mins.—excelsior pad on north portion of wall ignited. 5 hrs. 45 mins.—excelsior pad on south portion of wall giving off much smoke; was removed, charred, showing temperature was near ignition point.

After cooling.—Load of 80 lbs./in.² applied, producing some snapping sounds. Same for increases to 100 and 120 lbs./in.² also on release of load. No serious fire effects noted on unexposed side. Most of exposed gunite spalled off, except on upper 4 ft. of wall. Shells of tile and the mortar in lower part of wall fused. Detailed examination of individual units could not be made in dismantling this wall; however, it was observed that all exposed shells were loose. Masonry specimens were not taken for compression tests. (Condition shown in fig. 22.)

TEST No. 6.—16 by 11 ft.; 8-in. wall unplastered; unrestrained; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *d*. (Type 8–A–E, fig.

12a.)—1 to 10 mins.—many snapping sounds from wall. 10 mins.—two vertical cracks, following mortar joints, extend from top to bottom 1 and 2 ft. south of center, due apparently to small lateral overlap between tile units; these cracks opened gradually as the test progressed, until at 1 hr. 23 mins. they were open about ½ in. wide at top and ¼ in. at bottom of wall. 13 mins.—crack starting 5 ft. from top north corner and extending along mortar joints diagonally to the end of the wall; this crack opened gradually as the test progressed, until at 1 hr. 24 mins. it was open about ⅜ in. 25 mins.—steam coming from open mortar joints on unexposed side. 58 mins.—condensation at many points, distributed over lower part of unexposed side. 33 mins.—a few small flakes from unexposed side. 2 hrs. 35 mins.—a large amount of smoke from cotton pad; was removed at 2 hrs. 36 mins., when cotton burst into flame. 2 hrs. 40 mins.—a large amount of smoke from excelsior pad; burst into flame at 2 hrs. 45 mins.; pad was removed. 2 hrs. 53 mins.—fire shut off, as a temperature of 250° C. obtained on the unexposed surface. This is 1 hr. 27 mins. longer than the resistance period of the wall, as determined by temperature rise of 180.6° C. at a single point. The crack noted at 10 mins. was open slightly less than ½ in. at the top and about ⅛ in. at the bottom. The crack noted at 13 mins. was open about ¼ in. on unexposed side. (Temperature curves in fig. 58.)

After cooling.—In cooling, the crack formed at 10 mins. closed to ¼ in. at the top and $\frac{3}{32}$ in. at the bottom on the unexposed side. The crack noted at 13 mins. closed to ⅛ in. at the top. None of the exposed shells were off, and only a few small spalls had formed. In dismantling, however, it was found that the webs holding the exposed shells were cracked so that the shells could be easily pulled off. Generally, the damage did not extend beyond the center longitudinal web. A masonry specimen taken from this wall and tested in compression failed under a load of 300 lbs./in.² (Condition shown in fig. 23.)

Test No. 7.—4 by 4 ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *a–1*. (Type 8–A–E, fig. 12a.)—2 to 11 mins.—snapping and cracking sounds. 4 to 7 mins.—a crack appeared on the unexposed side, originating at the top near the middle and extending to the lower corner of the wall; this crack widened during test to ⅛ in. 22 mins. to 3 hrs. 20 mins.—other fine cracks, mostly vertical, appeared on the unexposed side of nearly all tile. 20 mins. to end of test—promiscuous cracking on exposed side, with spalling of ridges on several tile. 17 mins.—steam first appeared from an open mortar joint, increasing in volume until at 30 mins. it was coming from all upper mortar joints. 6 hrs.—fire shut off, which was 4 hrs. 36 mins. beyond the resistance period of the wall, as determined by the temperature rise on the unexposed surface. No overload was applied. (Temperature curves in fig. 59.)

After cooling.—No load applied. All shells in place, but fused on surface and loose. The cracking extended through the wall so that, in general, the unexposed shells were also loose. (Condition shown in fig. 21.)

Test No. 8.—8 by 10⅓ ft.; 8-in. wall plastered on exposed side with two coats of gypsum plaster. 80 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *d* laid with cells horizontal. (Type 8–A–S.)—18 mins.—a small amount of the second coat of plaster at south end of wall fell off. 18 to 25 mins.—many cracking sounds. 30 mins.—two fine vertical cracks following unexposed vertical mortar joints and breaking across intervening shells in lower portion of south end of wall. 1 hr. 20 mins.—exposed shell of hard tile 4 ft. from top and 2½ ft. from south end of wall spalling and throwing plaster off. 25 mins.—steam and condensation at unexposed mortar joints. 2 hrs. 50 mins.—small flakes from unexposed shells of hard tile. 3 hrs. 6 mins.—one tile spalled

through to unexposed side; fire shut off. 3 hrs. 12 mins.—load increased to 120 lbs./in.². No snapping during application. (Temperature curves in fig. 60.)

After cooling.—Load of 120 lbs./in.² was applied. No effects on unexposed side, except where one hard tile had spalled through from the exposed side. Only a small amount of plaster on exposed side off. This over a few tile that had spalled. Although all exposed shells were in place, 30 per cent of them were loose, and the webs holding 25 per cent of them were cracked. The remaining 45 per cent were in good condition or contained only minor cracks. In general, no cracks were found in or beyond the center longitudinal webs. A masonry specimen from this wall failed under a load of 275 lbs./in.² (Condition similar to wall 10 in fig. 24.)

TEST No. 9.—8 by 10⅓ ft.; 8-in. wall with gypsum plaster on both sides. 80 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *d*. (Type 8–A–E, fig. 12a.)—8 mins.—plaster over 2 sq. ft. in lower south corner bulging. 12 to 20 mins.—many snapping sounds. 50 mins.—spalling from exposed side of unit near south bottom of wall throwing off plaster. 58 mins.—exposed shell of very hard tile near center of wall spalling and throwing off plaster. 1 hr. 5 mins.—fine vertical crack in unexposed plaster extending 4 ft. upward from near lower north corner. 1 hr.—condensation at several places on unexposed surface. 1 hr. 30 mins.—steam coming from cracks and edges on unexposed side. 5 hrs. 3 mins.—cotton pad removed; did not flame, but cotton in contact with wall was charred and glowing. Fire shut off at 5 hrs. 30 mins., which was 1 hr. 24 mins. beyond the fire-resistance period, as determined by the temperature rise on the unexposed surface. 5 hrs. 37 mins.—load increased to 120 lbs./in.²; no cracking sounds when load was applied. (Temperature curves in fig. 61.)

After cooling.—Load of 120 lbs./in.² applied. Some snapping sounds during application. No serious fire effects apparent on unexposed side, although it was found that one hard tile had spalled through to the plaster, which later fell off. Brown coat of plaster on exposed side near south end over about 6 sq. ft. off. In addition, plaster at five places off from spalling of exposed shells of hard tile. Wall was repaired for a second fire test. (Condition shown in fig. 24.)

TEST No. 10.—8 by 10⅓ ft.; wall 9 repaired by removing occasional exposed shells, filling the exposed side cells with a mortar of fluid consistency, and replastering with gypsum plaster; 80 lbs./in.² load. 30 mins.—no effects noted. 1 hr.—considerable steam coming from unexposed side, part of it condensing on wall. 3 hr. 30 mins.—no effects noted other than vertical cracks on the unexposed surface, the most prominent of which was 1½ ft. from the north end of the wall and extends from top to bottom of wall, with a maximum width of $\frac{1}{16}$ in. 5 hrs. 30 mins.—large volume of steam continues to come from wall. Fire shut off. Load increased to 120 lbs./in.² without cracking sounds during application. (Temperature curves were not plotted.)

After cooling.—Load of 120 lbs./in.² carried without any apparent effect. Unexposed side stained at points where steam from wall condensed. Unexposed plaster contains numerous fine cracks. Nearly all exposed plaster in place but was calcined and contained fine cracks which, in general, outlined the units. A detailed examination of the units was not made in dismantling this wall; however it was observed that the exposed shells were loose, and that cracks did not extend beyond the center longitudinal web. (Condition shown in fig. 24.)

TEST No. 11.—4 by 4 ft.; 8-in. wall unplastered; restrained; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *d*. (Type 8–A–E, fig. 12a.)—8 mins. 30 mins.—snapping sounds, faint at first, but increasing in intensity during the 10 mins. 16 mins. to 1 hr.—spalling to depth of scoring on several exposed shells. 16 mins.—side and bottom joints along panel frame opened up to ¼ in. on unexposed side. 32 mins.—steam coming from open joints at edge of wall

1 hr. 5 mins.—steam coming from nearly all mortar joints. 1 hr. 30 mins.—fire shut off, this being the time limit for tests made to study effect of plaster. 1 hr. 32 mins.—many snapping sounds from cooling of wall. (Temperature curves in fig. 108.)

After cooling.—No fire effects on unexposed surface. Much spalling of ridges on exposed surface. All exposed shells were in place but loose, and some were cracked. Generally, the cracks did not extend beyond the center longitudinal web of the unit. (Condition shown in fig. 25.)

TEST No. 12.—4 by 4 ft.; 8-in. wall plastered on both sides with scratch and brown coat of gypsum plaster finished with a white coat; restrained; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *d*. (Type 8–A–E, fig. 12a.)—9 to 38 mins.—Occasional cracking sounds were heard. 24 mins.—checking of white coat with curling and spalling, so that at 1 hr. 30 mins. 50 per cent of white coat was off. 11 mins.—cracks in unexposed plaster appeared these spread and widened during the remainder of the test, until they outlined the units and in some cases had a width of $\frac{1}{16}$ in. 1 hr. 30 mins.—fire shut off, this being time limit for tests made to study effect of plaster; snapping sounds for a short time after the fire was shut off. (Temperature curves in fig. 108.)

After cooling.—Fine cracks on unexposed surface outline units; 50 per cent of finish coat from exposed surface off. About ½ sq. ft. of brown and scratch coat also off. None of the exposed shells were loose, although a part of the webs holding 60 per cent of them contained some cracks. The exposed surface of the shells contained very fine cracks, but these did not extend through the shell. (Condition similar to wall 59, shown in fig. 30.)

TEST No. 13.—4 by 4 ft.; 8-in. wall furred with tile on exposed side and plastered on both sides with two coats of plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction shale tile and 2 by 12 by 12 in. split furring tile, both from source *d*. (Type 8–AI–E, fig. 12c.)—20 mins. to 1 hr. 5 mins.—steaming and condensation at mortar joints on unexposed surface. 3 hrs.—only a small amount of steam now coming from wall. 1 hr.—indistinct cracking sounds. 3 hrs.—very fine horizontal crack in unexposed plaster over mortar joint at mid height of wall. 5 hrs. 1 min.—fire shut off to obtain subsequent temperature rise on unexposed surface. (Temperature curves in fig. 62.)

After cooling.—No fire effects on unexposed surface. Exposed plaster in place but contains cracks outlining mortar joints. Furring loose, due to calcining of mortar surrounding ties, but units of furring damaged only slightly. Structural part of wall (8 by 12 by 12 in. units) showed no effects from the fire. (Condition similar to wall 14, shown in fig. 25.)

TEST No. 14.—4 by 4 ft.; 8-in. wall furred with tile on exposed side and plastered on both sides with two coats of gypsum plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction shale tile and 2 by 12 by 12 in. split furring tile, both from source *d*. (Type 8–AI–E, fig. 12c.)—30 mins.—steam and condensation on upper unexposed surface. 1 hr. 15 mins.—moisture spots on lower unexposed surface; no further effects noted during test. 6 hrs. 6 mins.—fire shut off, as the resistance period, as determined by the temperature rise on the unexposed surface, was reached at 6 hrs. 5 mins. (Temperature curves in fig. 63.)

After cooling.—No fire effects on unexposed surface. All exposed plaster in place, but cracks outline mortar joints. Furring not broken up, but ties were pulled slightly from wall and had no bond with furring, due to the calcining of mortar. Structural part of wall (8 by 12 by 12 in. units) showed no effects from the fire. (Condition shown in fig. 25.)

TEST No. 15.—8 by 10⅓ ft.; 8-in. wall plastered on both sides with gypsum plaster; 80 lbs./in.² load; double shell 8 by 12 by 5 in. shale tile from source *d*. (Type 8–E–E.)—8 to 20 mins.—snapping sounds. 23 to 30 mins.—about 1

sq. ft. of exposed plaster at each of four places at bottom, middle, and top of wall buckled and thrown off by spalling of hard tile. 1 hr.—condensation of steam from wall at various places on unexposed surface. 4 hrs. 24 mins.—cotton pad removed; about 6 sq. in. of exposed shell and plaster on unexposed side fell off when pad was removed, showing hole in wall; cotton charred and glowing only in lower part, which was opposite shattered tile. 5 hrs. 30 mins.—fire shut off, which was 3 hrs. 21 mins. beyond the resistance period, as determined by the temperature rise on the unexposed surface. 5 hrs. 37 mins.—load increased to 120 lbs./in.² with no apparent effect. (Temperature curves in fig. 64.)

After cooling.—Load of 120 lbs./in.² carried with a small amount of snapping during load application. No decided fire effects on unexposed side, except the hole formed by spalling. Plaster on exposed side off at several places, due to spalling and flaking of exposed shells. Wall was repaired for a second fire test. (Condition shown in fig. 24.)

TEST No. 16.—8 by 10⅓ ft.; wall 15 repaired by removing occasional exposed shells, filling the cells with a mortar of fluid consistency, and replastering with gypsum plaster; 80 lbs./in.² load. 30 mins.—no effects noted. 1 hr.—much steaming from unexposed side of wall; steam condensing and forming wet spots on all parts of unexposed surface; this continued throughout the test. 5 hrs. 30 mins.—fire shut off, as time limit of previous test had been reached. Load increased to 120 lbs./in.² without apparent effects. (Temperature curves not plotted.)

After cooling.—Load of 120 lbs./in.² carried without apparent effects. Entire unexposed side stained from condensation of steam. All exposed plaster in place but was calcined and contained fine cracks which, in general, outlined the units. A detailed examination of the units was not made in dismantling this wall, but it was noted that all of the outer exposed shells were loose, and in some cases the inner shell of the double-shell tile was also loosened. (Condition shown in fig. 24.)

TEST No. 17.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; 3-cell 8 by 5 by 12 in. side-construction shale tile from source *c*. (Type 8–K–S, fig. 12b.)—1 to 7 mins.—many snapping sounds were heard. 18 mins.—spalling at mortar joints on lower part of exposed side from loosening of exposed shells. 30 mins.—two exposed shells in lower middle portion of wall loose and bulging. 50 mins.—loosened shells bulge out 1 in. 48 to 55 mins.—vertical cracks at middle of six unexposed shells near top of wall. 45 mins.—steam coming from unexposed side mortar joints. 1 hr. 15 mins.—hydraulic jack leaking so that load could not be applied, but fire exposure was continued; jack repaired and at 1 hr. 32 mins. applied load of 95 lbs./in.², causing failure. In failing, many exposed shells fell off, and portion of wall near top moved away from the fire about 2 ins. (Temperature curves shown in fig. 65.)

TEST No. 18.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; 2-cell 8 by 5 by 12 in. side-construction shale tile from source *d–2*. (Type 8–L–S.)—2 mins.—many snapping sounds. 1 hr. 55 mins.—vertical crack across one unit and along vertical mortar joint near middle of unexposed side of wall; no fire effects on exposed side were noted. 2 hrs. 15 mins.—fire shut off, as resistance period, as determined by temperature rise, was reached at 1 hr. 49 mins. In applying the overload the upper portion of the wall buckled and fell out when a load of approximately 110 lbs./in.² was reached. (Temperature curves in fig. 65.)

After cooling.—The condition of the units indicated that the fire loosened the exposed shells, and generally the cracking did not extend beyond the center longitudinal web.

TEST No. 19.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction shale tile from source *d–1*. (Type 8–O–S, fig. 12b.)—2 to 15 mins.—many snapping sounds. 25 mins.—spalling on about 20 sq. in. area from exposed shell of one unit near top of wall. 18 mins. to 1 hr. 10 mins.—vertical cracks appeared on the unexposed side of many units; these cracks most frequent on the units having the large face exposed to the fire. 25 mins. to end of test—steam coming from mortar joints on the unexposed side. 1 hr. 30 mins.—fire shut off to determine effect of short fire exposure; some snapping sounds after fire was shut off. (Temperature curves in fig. 66.)

After cooling.—Carried 80 lbs./in.² load. Exposed surface covered with fine cracks which, in general, were vertical. Although the exposed shells were in place, the webs holding them were cracked so that the shells could be easily removed. In addition, vertical cracks divided about 25 per cent of the units into two lengths. (Condition silmiar to wall 20, shown in fig. 25.)

TEST No. 20.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction shale tile from source *d–1*. (Type 8–O–S, fig. 12b.)—4 to 15 mins.—many snapping sounds. 16 mins.—spalling on about 8 sq. in. area near top of exposed side. 20 mins.—further spalling on about 20 sq. in. area. 17 mins.—vertical cracks appearing near mid length of many unexposed shells. 25 mins. to end of test—steam condensation on unexposed side mortar joints. 1 hr. 30 mins.—fire shut off to determine effect of short fire exposure. (Temperature curves, in fig. 66.)

After cooling.—Exposed surface covered with fine cracks which, in general were vertical. Although the exposed shells were in place, the webs holding, them were cracked so that the shells could be easily removed. In addition, vertical cracks divided about 25 per cent of the units into two lengths. (Condition shown in fig. 25.)

TEST No. 21.—8 by 10⅓ ft.; 8-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction shale tile from source *d–1*. (Type 8–O–S, Fig. 12b.)—½ min.—snapping sounds were heard. 5 and 6 mins.—two major vertical cracks extending from top to bottom along vertical mortar joints and breaking across intervening tile formed near the middle of unexposed surface. 12 mins.—steam coming from cracks and imperfect mortar joints, increasing in volume as test proceeds; no steaming after 2 hrs. 30 mins. 3 hrs. 20 mins.—cotton pad removed; cotton was charred and glowing but did not flame. 4 hrs. 25 mins.—fire was shut off because of shutdown of the compressor supplying the air for the burners; this test was continued 1 hr. 28 mins. beyond the resistance period of the wall, as determined by the temperature rise on the unexposed surface. 4 hrs. 30 mins.—the load was increased until, when 112 lbs./in.² was reached, the wall failed, falling outward. (Temperature curves in fig. 67.)

After cooling.—Detailed examination of the individual units could not be made, as, in general, the entire units were broken up.

TEST No. 22.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; H-shaped 8 by 10¼ by 12 in. side-construction shale tile from source *c–1*. (Type 8–P–S, fig. 12c.)—2 to 5 mins.—continuous snapping sounds, with occasional loud cracking up to 27 mins. 15 mins.—one exposed shell near middle of wall loose and bulged slightly. 15 to 25 mins.—several small spalls from lower portion of exposed surface. 22 to 45 mins.—several vertical mortar joints near top opened slightly. 4 hrs. to end of test—vertical cracks formed at middle of unexposed shells of many tile. 46 mins.—steam coming from mortar joints at top of wall. Fire shut off at 6 hours, which was 4 hrs. 4 mins. beyond the fire-resistance period of the wall. No additional load applied. (Temperature curves in fig. 68.)

After cooling.—Both the exposed and unexposed sides of the wall were cracked so that all exposed shells were loose. There was considerable cracking during

the application of the load, with failure by buckling near the top at load of about 70 lbs./in.² (Condition similar to Wall 23, shown in fig. 25.)

TEST No. 23.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; H-shaped 8 by 10¼ by 12 in. side-construction shale tile from source *c–1*. (Type 8–P–S, fig. 12c.)—1 min.—snapping and cracking sounds heard. 2 to 15 mins.—spalls to depth of scoring on about 30 per cent of lower portion of exposed surface. 1 hr. 12 mins. to 1 hr. 20 mins.—vertical cracks on surface of two unexposed shells. 45 mins.—steam coming from unexposed mortar joints. 1 hr. 30 mins.—fire shut off to determine damage to units by short fire exposure. 1 hr. 31 mins.—many snapping sounds. This continued intermittently for about 15 mins. (Temperature curves in fig. 68.)

After cooling.—Carried 80 lbs./in.² load, apparently with some margin. Promiscuous cracks on exposed surface of wall. All exposed shells in place but loose. No cracks were found in or beyond the first longitudinal web. (Condition shown in fig. 25.)

TEST No. 24.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; cube-shaped 9-cell 8 by 8 by 8 in. side-construction shale tile from source *d*. (Type 8–Q–S, fig. 12b.)—10 mins.—spalling from several exposed shells in bottom center of wall. 1 hr. to 1 hr. 25 mins.—three exposed shells in lower west corner of wall loose and bulged toward fire about 1 in. 1 hr. 25 mins. to 1 hr. 40 mins.—vertical cracks on unexposed shells near middle of wall; these cracks are opposite vertical mortar joints above and below them. 1 hr. 50 mins.—crack near west end of unexposed surface, following both vertical and horizontal mortar joints and extending from near top to near bottom of wall. 30 mins. to 1 hr. 30 mins.—steam condensing on unexposed morter joints. 2 hrs. 23 mins.—fire shut off, as resistance period of the wall, as determined by the temperature rise on the unexposed surface, had been nearly obtained. Load was increased to 120 lbs./in.² without much snapping or cracking. (Temperature curves in fig. 69.)

After cooling.—Only minor cracks visible on unexposed side. Four exposed shells near bottom of wall off. Load of 80 lbs./in.² was carried; many snapping sounds during its application. When the load was increased to 104 lbs./in.² the wall failed under load, buckling outward near middle. In dismantling, it was found that all of the exposed shells were loose. Some units were also damaged near the unexposed side, due most probably to load application after the fire was shut off.

TEST No. 25.—8 by 10⅓ ft.; 8-in. wall plastered on exposed side with gypsum plaster; 80 lbs./in.² load; 9-cell cube-shaped 8 by 8 by 8 in. side-construction shale tile from source *d*. (Type 8–Q–S, fig. 12b.)—10 to 25 mins.—many snapping sounds. 3 hrs. 6 mins.—no further fire effects; fire shut off, as resistance period of companion wall (No. 8) was reached. 3 hrs. 12 mins.—load increased to 120 lbs./in.² No snapping or cracking sounds in applying additional load. (Temperature curves in fig. 70.)

After cooling.—Load of 120 lbs./in.² carried. Snapping sounds were heard during the application of the last increments of load. No fire effects on unexposed side. All plaster in place, except in top north corner. A few shells at this point were off, probably coming off at the time of applying the overload; 22 per cent of the exposed shells were loose, and the webs holding 31 per cent of them had decided cracks. The remaining 47 per cent of the units were in good condition or contained only minor cracks. In general, no cracks were found in or beyond the first longitudinal web. A masonry specimen cut from this wall failed under a load of 280 lbs./in.²

TEST No. 26.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load. 6-cell 8 by 8 by 12 in. H-shaped side-construction shale tile from source *a*. (Type 8–R–S.)—8 mins. to 2 hrs. 45 mins.—vertical cracks appeared on unexposed shells of

about one-half of the units, usually at the middle of the shell. 15 mins.—small spall fell from an exposed shell in lower portion of wall. 18 mins.—exposed shells in lower two courses of wall fell off. 1 hr. 30 mins.—considerable cracking of tile. Fire shut off at 3 hrs. 12 mins., which was 1 hr. 59 mins. beyond the resistance period of the wall. 3 hrs. 17 mins.—load increased to 120 lbs./in.^{2} with some snapping sounds, but no additional shells fell off. (Temperature curves in fig. 71.)

After cooling.—Nearly all of exposed shells fell off, and failure was approached under a load of 30 lbs./in.^{2}. Remainder of exposed shells were loose. Cracks extended into the wall so that nearly all of the units were shattered. (Condition shown in fig. 26.)

Test No. 27.—4 by 4 ft.; 8-in. wall plastered on exposed side with gypsum plaster; 80 lbs./in.^{2} load; 6-cell 8 by 8 by 12 in. H-shaped side-construction shale tile from source *a*. (Type 8–R–S.)—Plaster "dried out," due to unduly long time of set of plaster. 4 mins.—about 75 per cent of the brown coat of plaster fell off. 20 mins.—about ⅛ sq. ft. of the scratch coat of plaster fell off. 25 mins. to 1 hr. 30 mins.—vertical cracks appeared on the unexposed shells in the upper portion of the wall. 55 mins.—condensation of steam on unexposed mortar joints in the upper portion of the wall. 1 hr.—occasional snapping and cracking sounds were heard. Fire shut off at 6 hrs., which was 3 hrs. 11 mins. beyond the resistance period of the wall. Load was increased to 120 lbs./in.^{2} (Temperature curves in fig. 72.)

After cooling.—Load of 120 lbs./in.^{2} was applied; some snapping sounds during the application of the load. Nearly all of plaster on the fire side had fallen off during the test, but what remained showed some fusion. All of the exposed shells were in place, but the webs holding them were cracked so that the shells were loose. These cracks extended beyond the first longitudinal webs of about 30 per cent of the units. (Condition shown in fig. 25.)

Test No. 28.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.^{2} load; 3-cell double-shell 8 by 3½ by 12 in. side-construction shale tile from source *d–3*. (Type 8–T–S.)—2 mins.—many cracking sounds. 12 mins.—three small spalls from near middle of exposed surface. 26 mins.—exposed shells of four courses near top loosened and bulged 2½ in. toward fire. 3 hrs.—exposed shells of eight of the units previously bulging fell off. 1 hr. 25 mins. to 2 hrs. 30 mins.—vertical cracks formed on most of units in upper portion of unexposed side, usually at middle of unit; two prominent cracks extended from top of wall downward across middle, following vertical mortar joints and breaking across intervening units; maximum width of cracks at 2 hrs. was 1/16 in. 22 mins.—steam condensing on mortar joints at eight places in upper portion of unexposed side. 2 hrs. 15 mins.—no further steam or condensation on wall. Fire shut off at 3 hrs. 56 mins., which was 1 hr. 33 mins. beyond the resistance period of the wall. Load increased to 120 lbs./in.^{2} A number of snapping sounds during load application. (Temperature curves in fig. 73.)

After cooling.—No record of loading. All exposed shells were off, except those of lower two courses, which were loose. The double shells always came off together, no fracture occurring between the inner and the outer shell. In addition, about 50 per cent of the units in the upper portion of the wall were broken into two lengths. (Condition shown in fig. 26.)

Test No. 29.—4 by 4 ft.; 8-in. wall plastered on exposed side with gypsum plaster; 80 lbs./in.^{2} load; 3-cell double-shell 8 by 3½ by 12 in. side-construction shale tile from source *d–3*. (Type 8–T–S.)—Plaster partially "dried out," due to unduly long time of set of the plaster. 1 min.—plaster started to buckle at various places. 9 mins.—all plaster in lower 3 ft. of wall off. 12 mins.—remainder of plaster off. 10 mins.—many cracking sounds were heard. 12 mins.—

small spalls 1 in. wide and 1 to 6 in. long from scattered points over exposed surface. 36 mins. to 2 hrs. 25 mins.—vertical cracks across middle of unexposed shells in upper portion of wall. 26 mins.—steam condensation on mortar joints in upper portion of unexposed side. Fire shut off at 4 hrs. 44 mins., which was 2 hrs. 12 mins. beyond the resistance period of the wall. Load increased to 120 lbs./in.,^{2} with no snapping sounds during load application. (Temperature curves in fig. 74.)

After cooling.—No record of loading. All plaster off. All exposed shells in place but loose. No cracks were found between the inner and outer shells. Except for the vertical cracks dividing the units into two lengths, no cracks were found in or beyond the first web. (Condition shown in fig. 26.)

TEST No. 30.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.^{2} load; 2-cell double-shell 8 by 5 by 12 in. side-construction shale tile from source *d–3*. (Type 8–S–S.)—(Plaster had been placed on the exposed side of this wall, but it had "dried out" and fell off within 6 mins. after the start of the test. This wall is therefore listed as unplastered.) 10 to 23 mins.—snapping and cracking sounds. 30 mins.—a few small spalls 1 in. wide and 1 to 6 in. long from scattered parts of exposed surface. 47 mins.—loud cracking was heard. 30 mins.—first condensation on unexposed side mortar joints. 1 hr. 55 mins.—no further steam coming from wall. 1 hr. 40 mins. to 3 hrs. 15 mins.—vertical cracks appeared across middle of 40 per cent of shells in upper portion of wall. Fire shut off at 3 hrs. 36 mins., which was 1 hr. 32 mins. beyond the resistance period of the wall. No additional load. (Temperature curves in fig. 75.)

After cooling.—Load of 120 lbs./in.^{2} carried. Many snapping sounds during the application of the last 40-lb. increment of load. All of the exposed shells were in place but were loose, so that they could be easily removed. Except for the vertical cracks dividing some units in the upper portion of the wall into two lengths, no cracks were found in or beyond the center longitudinal web. (Condition shown in fig. 26.)

TEST No. 31.—4 by 4 ft.; 8-in. wall plastered on exposed side with gypsum plaster; 80 lbs./in.^{2} load; 2-cell double-shell 8 by 5 by 12 in. side-construction shale tile from source *d–3*. (Type 8–S–S.)—12 mins.—some cracking and snapping sounds were heard; no fire effects on plaster. 1 hr. 10 mins.—vertical crack at center of wall 2½ ft. long. 1 hr. 20 mins.—diagonal crack following unexposed side mortar joints extends across one top corner of wall. 27 mins.—first condensation on unexposed side mortar joints. Fire shut off at 6 hrs., which was 3 hrs. 25 mins. beyond the resistance period of the wall. Load increased to 120 lbs./in.^{2} (Temperature curves in fig. 76.)

After cooling.—Load of 120 lbs./in.^{2} applied. No cracking sounds during load application. All plaster in place. It contains no shrinkage cracks, but surface of plaster slightly fused. The webs holding the exposed shells of nearly all tile were cracked so that the shells were loose. No cracks, except the vertical cracks dividing some units into two lengths, were found in or beyond the center longitudinal web.

TEST No. 32.—4 by 4 ft.; 8-in. wall unplastered; 120 lbs./in.^{2} load; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *j*. (Type 8–A–E, fig. 12a.)—4 to 40 mins.—frequent cracking sounds. 40 mins. to end of test—occasional cracking sounds. 10 mins.—crack $\frac{3}{16}$ to ¼ in. wide, from top near west end of unexposed surface to near bottom of wall. 31 mins.—crack $\frac{1}{32}$ in. wide forming in unexposed side near bottom east corner; other minor vertical cracks in unexposed shells near middle of wall. 14 mins.—spalling from one exposed shell. 1 hr. 8 mins.—spalling from exposed mortar joints in lower west section. 37 mins. to 1 hr. 19 mins.—steam from several unexposed mortar joints. 1 hr. 20 mins.—bulging of shells on unexposed surface in lower west

corner. 1 hr. 37 mins.—wall failed under load, with buckling outward of lower west portion; exposed shells in this portion also off. (Temperature curves in fig. 77.)

After cooling.—All exposed shells off or loose. Remaining portion of units cracked.

TEST No. 33.—4 by 4 ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *j*. (Type 8–A–E, fig. 12a.)—2 mins.—snapping sounds started; were heard occasionally throughout test. 4 to 18 mins.—spalling from exposed surface. 15 mins.—steam from top mortar joint. 17 mins.—exposed shells in upper portion of wall bulging. 40 mins.—four exposed shells near top of wall fell off. 11 mins.—vertical cracks began forming on unexposed surface, the most prominent ones being up to ¼ in. wide in upper west corner. 1 hr. 30 mins.—fire shut off to determine effect of short exposure; wall still carrying load. (Temperature curves in fig. 77.)

After cooling.—Load not applied. All exposed shells were off, except those in bottom course, which were loose. Cracks on unexposed surface, generally, extend from upper middle of wall downward. Nearly all of the units were damaged by cracks in and beyond the center longitudunal web. (Condition similar to that of wall 121, shown in fig. 45, except that no fusion occurred.)

TEST No. 34.—8 by 10⅓ ft.; 8-in. wall unplastered; 120 lbs./in.² load; 9-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *j*. (Type 8–C–E.)—2 mins.—many cracking sounds; this continued intermittently throughout test. 3 to 9 mins.—spalling on exposed surface; spalls have thickness equal to depth of scoring and usually start from ends of units. 18 mins.—steam and condensation on unexposed surface. 25 mins.—exposed shells of third and fourth courses from top bulging. 30 mins.—several prominent vertical cracks appear on unexposed side, follow vertical mortar joints and across intervening units. 37 mins.—shells of third, fourth, and fifth courses bulging; cracking and gradual crumbling of mortar indicate early failure. 44½ mins.—failure started; load removed to prevent collapse of wall. 45 mins.—fire shut off. (Temperature curves not plotted.)

After cooling.—No appreciable load could be carried; 30 per cent of the exposed shells were off, the remaining 70 per cent being loose. A small percentage of the units in the lower part of the wall were cracked in and back of the first longitudinal web. No damage extended beyond the second longitudinal web. (Condition similar to wall 35, shown in fig. 27.)

TEST No. 35.—8 by 10⅓ ft.; 8-in. wall unplastered; 120 lbs./in.² load; 1:3 cement mortar tempered with 15 per cent of lime; 9-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *j*. (Type 8–C–E.)—2 mins.—cracking sounds were heard. 3 to 9 mins.—spalling on exposed surface, spalls having thickness equal to depth of scoring and usually starting from ends of units. 18 mins.—steam from open joints on unexposed side. 20 mins.—several vertical cracks on unexposed surface. 28 mins.—part of the exposed shells of third and fourth course off; remainder of shells of these courses loose and buckled. 44½ mins.—considerable cracking; early failure indicated; load removed. 45 mins.—fire shut off. (Temperature curves not plotted.)

After cooling.—No appreciable load could be carried. About 50 per cent of exposed shells were off. Many longitudinal webs also off. Remainder of shells loose. No units had any salvage value. This wall was identical with wall 34, except for mortar. No difference in fire effects ascribable to the difference in mortar was noted. (Condition shown in fig. 27.)

TEST No. 36.—8 by 11 ft.; 8-in. wall plastered on exposed side with gypsum plaster; restrained; 9-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *j*. (Type 8–C–E.)—17 mins.—snapping and cracking sounds were

heard. Steam coming from open mortar joints on unexposed side. 25 mins.—much snapping heard. 3 hrs.—a small amount of steam still coming from open mortar joints. Fire shut off at 6 hrs., which was 1 hr. 18 mins. beyond resistance period of wall. No cracks noted. 6 hrs. 20 mins.—smoke coming from excelsior-filled box. 6 hrs. 48 mins.—excelsior-filled box removed; it burst into flame as it was taken off wall. (Temperature curves in fig. 78.)

After cooling.—All plaster in place, but covered with cracks outlining the units. All of the exposed shells were loosened so that they could be pulled off, but, in general, no cracks were found in or beyond the first longitudinal web. A masonry specimen out from this wall failed under a load of 350 lbs./in.^{2} (Condition shown in fig. 27.)

TEST No. 37.—8 by 11 ft.; 8-in. wall plastered on both sides with cement plaster; restrained; 9-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *j*. (Type 8–C–E.)—17 to 25 mins.—some snapping and cracking sounds were heard. 30 mins.—wet spots appearing on unexposed surface of wall. 40 mins.—bottom center of wall raised up and moved toward fire about $\frac{1}{32}$ in. Fire shut off at 6 hours, which was the time limit for tests in the large furnace. No effects on excelsior-filled box. (Temperature curves in fig. 79.)

After cooling.—No effects were noted on unexposed side. Except for 3 sq. ft. of outer coat near bottom of wall, all plaster on exposed side was in place, but cracks outlined the units. All of the exposed shells were loosened so that they could be pulled off, but, in general, no cracks were found in or beyond the first longitudinal web. A masonry specimen cut from this wall failed under a load of 255 lbs./in.^{2} (Condition similar to wall 36, shown in fig. 27.)

TEST No. 38.—8 by 10⅓ ft.; 8-in. wall unplastered; 70 lbs./in.^{2} load; 9-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *j*. (Type 8–C–E.)—3 mins.—many snapping and cracking sounds. 25 mins.—steam coming from unfilled unexposed side mortar joints. 35 mins.—spalls to depth of scoring falling from some exposed shells. 1 hr. 45 mins.—vertical crack following vertical mortar joints and breaking across tile extends over one-half height near middle of unexposed side. 3 hrs. 31 mins.—fire shut off, as the resistance period of the wall was reached at 3 hrs. 27 mins. 3 hrs. 32 mins.—load increased to 105 lbs./in.^{2} (50 per cent overload), with slight amount of snapping. (Temperature curves in fig. 80.)

After cooling.—Load of 70 lbs./in.^{2} carried, with a few cracking sounds. 120 lbs. was applied, a considerable number of cracking sounds being heard during the application. There was no effect on the unexposed side, except the crack noted at 1 hr. 45 mins. All exposed shells were in place, but a few of them had spalled to the depth of the scoring; 93 per cent of the exposed shells were loosened, and the webs holding the remainder of them were severely cracked. No cracks were formed beyond the first longitudinal web. A masonry specimen cut from this wall failed under a load of 160 lbs./in.^{2} (Condition shown in fig. 27.)

TEST No. 39.—8 by 10⅓ ft.; 8-in. wall plastered on the exposed side with gypsum plaster; 70 lbs./in.^{2} load; 9-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *j*. (Type 8–C–E.)—25 mins.—steam coming from some open mortar joints on exposed side. 3 hrs. 31 mins.—fire shut off, as resistance period of companion wall (No. 38) had been reached. 3 hrs. 32 mins.—load increased to 105 lbs./in.^{2} (50 per cent overload) without cracking sounds. (Temperature curves in fig. 81.)

After cooling.—Loads up to 120 lbs./in.^{2} were applied without serious cracking and 180 lbs./in.^{2} was applied without failure. No fire effects were observed on unexposed surface. All of the plaster on the exposed side was in place but contained cracks which outlined the units. In dismantling the wall, it was found that 27 per cent of the exposed shells were loose, and that the webs holding

the remainder of them were cracked, but the shells were not loose. No cracks were found in or beyond the first longitudinal web. Two masonry specimens cut from this wall gave an average unit compressive strength of 195 lbs./in.² (Condition similar to that of wall 36, shown in fig. 27.)

TEST No. 40.—4 by 4 ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *r*. (Type 8–A–E, fig. 12a.)—7 mins.—faint cracking sounds. 13 mins.—a small spall from exposed side of one tile in lower portion of wall. 28 mins.—the exposed shells fell from the top portion of the wall; all other exposed shells loose; load dropped to about 80 lbs./in.²; the load could not be increased. 33 mins.—fire shut off because of failure under load. 35 mins.—additional exposed shells fell off. (Temperature curves in fig. 82.)

After cooling.—No attempt to apply load was made. All exposed shells were off, and many of the unexposed shells in the middle of the wall were broken up. The cracking was due in part to the failure of the wall under load.

TEST No. 41.—4 by 4 ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *r*. (Type 8–A–E, fig. 12a.)—8 to 15 mins.—loud cracking sounds. 9 mins.—spall from the exposed shell of a soft tile near the center of the wall. 14 mins.—cracks formed on the unexposed side of one tile near center of wall. 18 mins.—exposed shells of top part of wall loose and bulged toward fire. 28 mins.—further bulging of exposed shells. 1 hr. 30 mins.—fire shut off to determine effect of short exposure. Wall continues to carry applied load. All shells were in place, but many of them were buckled. (Temperature curves in fig. 82.)

After cooling.—No attempt was made to apply load. Many of the exposed shells were off. All others were loose. Generally cracks did not extend beyond center longitudinal web.

TEST No. 42.—16 by 11 ft.; 8-in. wall unplastered; unrestrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E.)—2 mins.—snapping and cracking sounds coming from wall. 15 mins.—steam from mortar joints near top and middle of wall. 17 mins.—ridges in lower part of exposed side spalled. 10 mins. to 1 hr. 30 mins.—cracks forming on unexposed surface, in a general vertical direction and extending along mortar joints. 2 hrs. 41 mins.—cracks closing up, furnace glow seen through one at lower middle of wall. 2 hrs. 30 mins.—a large amount of smoke now coming from cotton pad. 2 hrs. 47 mins.—cotton pad was removed; about one-third of cotton was consumed, but remainder did not burst into flame when exposed to the air. 2 hrs. 37 mins.—smoke from excelsior-filled box. 3 hrs. 44 mins.—a large amount of smoke from same. Fire shut off at 4 hrs. 12 mins., which was 1 hrs. 14 mins. beyond the fire-resistance period of the wall. (Temperature curves in fig. 83.)

After cooling.—None of the exposed shells were off. The webs holding 28 per cent of the exposed shells were cracked so that the shells could be easily pulled off. The webs holding 44 per cent of the exposed shells were also cracked, but the shells were not loose; 28 per cent of the units were in good condition or contained only minor cracks. A masonry specimen cut from this wall and tested in compression failed under a load of 220 lbs./in.² (Condition shown in fig. 28.)

TEST No. 43.—8 by 10⅓ ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—5 to 20 mins.—snapping and cracking sounds were heard. 30 mins. to 1 hr. 55 mins.—steam coming from mortar joints on unexposed side. 55 mins.—spalling from surface of many exposed shells, spalls extending to maximum depth of ½ in. 20 mins.—diagonal crack 4 ft. long from point 4 ft. above bottom corner, extending mainly along mortar joints. 25 to 38 mins.—

vertical crack formed on unexposed side parallel to and about 2 ft. from edge o wall. 2 hrs. 20 mins.—smoke coming from excelsior-filled box. 2 hrs. 43-mins.- excelsior-filled box removed; part of box in contact with wall was charre Fire shut off at 3 hrs. 51 mins., which was 1 hr. 58 mins. beyond the resistanc period of the wall. 3 hrs. 58 mins.—load increased to 180 lbs./in.² Crackin noted in one upper corner. (Temperature curves in fig. 84.)

After cooling.—Load of 120 lbs./in.² was applied. A number of crackin sounds during application. All of the exposed shells were in place but loos and their surfaces were spalled. Generally no cracks were formed in or back o center longitudinal web. No masonry specimens were taken from this wall fo compression test.

TEST No. 44.—8 by 10⅓ ft.; 8-in. wall unplastered; 120 lbs./in.² load; 1: cement mortar tempered with 15 per cent lime; 6-cell 8 by 12 by 12 in. en construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—5 to 2 mins.—snapping sounds heard. 10 mins. to 1 hr. 55 mins.—steam coming fro mortar joints on unexposed side. 15 mins.—spalling from surface of ma shells on exposed side. Spalls extending to maximum depth of ½ in. 8 mins.- diagonal crack about 3 ft. long extending across lower corner of unexposed sid 20 mins.—vertical crack on unexposed side, running from middle of top ed downward about 4 ft. 3 hrs. 30 mins.—glowing can ben seen through seve unfilled vertical mortar joints. 2 hrs. 25 min.—a small amount of smo coming from cotton pad. 2 hrs. 58 mins.—cotton pad removed; cotton char and glowing in spots. Fire shut off at 3 hrs. 51 mins., which was 1 hr. 53 mi beyond the fire-resistance period of the wall. 3 hrs. 58 mins.—load of 180 lbs./i was applied without serious cracking. (Temperature curves in fig. 85.)

After cooling.—Load of 120 lbs./in.² was applied with only small amount cracking. Load increased to 180 lbs./in.² without additional cracking. All the exposed shells were in place, but their surfaces were spalled. Also, all expos shells were loose, but generally no cracks were formed in or back of center lon tudinal web. No masonry specimens were taken from this wall for compressi test.

TEST No. 45.—8 by 11 ft.; 8-in. wall plastered on the exposed side with gypsu plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile fr source *k*. (Type 8–B–E.)—45 mins.—small areas of second coat of plas spalled in three places. 50 mins.—steam began coming from open mortar joi near top of wall. 1 hr. 25 mins.—large volume of steam now coming from w 1 hr. 20 mins.—outside bottom center of wall arched up about $\frac{1}{16}$ in. and mov toward the fire about $\frac{1}{16}$ in. 3 hrs. 46 mins.—a small amount of smoke com from cotton pad. 4 hrs. 17 mins.—cotton pad was removed; did not blaze, b all cotton in contact with the wall was charred and smoldering. Fire shut at 6 hrs., which was 2 hrs. 41 mins. beyond the fire-resistance period of wa (Temperature curves in fig. 86.)

After cooling.—No fire effects were observed on the unexposed side. Abo 2 sq. ft. of the second coat of plaster were off, the remainder being in place b calcined and covered with a network of fine cracks. In dismantling the wa it was found that 6 per cent of the units were in good condition or contained on minor cracks; 53 per cent had some of the webs holding the exposed shells cracke but the shells were not loose; 37 per cent had their exposed shells loose; and per cent contained cracks back of the center longitudinal web. A masonr specimen cut from this wall and tested in compression failed under a load 380 lbs./in.² (Condition similar to that of wall 36, shown in fig. 27.)

TEST No. 46.—8 by 11 ft.; 8-in. wall plastered on both sides with cem plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay t from source *k*. (Type 8–B–E, fig. 12a.)—8 mins.—snapping sounds heard fr

wall, but no cracks were noted. 50 mins.—condensation noted on unexposed side at mortar joint near mid height of wall. 1 hr. 25 mins. and 1 hr. 37 mins.—condensation at additional points on unexposed side. 1 hr. 18 mins.—diagonal crack about 3 ft. long across top corner of wall. 1 hr. 20 mins.—outside bottom center of wall arched up about $\frac{1}{16}$ in. and moved toward fire $\frac{3}{16}$ in. 3 hrs. 56 mins.—smoke coming from cotton pad. 4 hrs. 12 mins.—cotton pad removed; all cotton in contact with the wall was charred or smoldering but did not blaze. Fire shut off at 6 hrs., which was 2 hrs. 15 mins. beyond the resistance period of the wall. (Temperature curves in fig. 87.)

After cooling.—All plaster in place, and that on the exposed side was covered with a network of fine cracks, the general direction of which was vertical. In dismantling the wall, it was found that 20 per cent of the units had some of the webs holding the exposed shells cracked, but the shells were not loose; that 77 per cent of the units had their exposed shells loosened; and that 3 per cent had cracks back of the center longitudinal web in addition to having the exposed shells loose. A masonry specimen cut from this wall and tested in compression failed under a load of 215 lbs./in.^{2} (Condition similar to that of wall 36, shown in fig. 27.)

Test No. 47.—4 by 4 ft.; 8-in. wall unplastered; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—2 mins.—snapping sounds were heard. 4 to 16 mins.—spalling of tile ridges on exposed side of lower portion of wall. 15 mins.—crack forming along unexposed side horizontal mortar joint at mid height of wall. 55 mins.—steam coming through imperfect mortar joints on unexposed side. 1 hr. 30 mins.—fire shut off. This test limit was chosen to obtain the effect of plaster in reducing the fire effects of short exposures. (Temperature curves in fig. 88.)

After cooling.—No fire effects were noted on the unexposed side. The exposed surface of tile on the lower part of wall was spalled to depth of scoring. Although the exposed shells were in place, the webs holding them were cracked so that the shells were loose or could be easily pulled off. Generally no cracks extended beyond the center longitudinal web. (Condition shown in fig. 29.)

Test No. 48.—4 by 4 ft.; 8-in. wall plastered on both sides with cement plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—10 to 30 mins.—exposed plaster at one place appears to be loose and buckling. 27 to 45 mins.—fine horizontal crack developing at mid height of unexposed side. 1 hr. 30 mins.—fire shut off. (Temperature curves in fig. 88.)

After cooling.—No fire effects were noted on the unexposed side, except one fine horizontal crack at mid height of wall. All exposed plaster was in place but was covered with fine cracks which, in general, outlined the units. Plaster was very hard and, except at one point, where it had buckled, it was difficult to remove. About 20 per cent of the shells were loose, and the remainder of the units had cracks in some of the webs holding the exposed shells, but the shells were not loose. (Condition shown in fig. 29.)

Test No. 49.—4 by 4 ft.; 8-in. wall plastered on both sides with two coats of gypsum plaster finished with a white coat; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—2 mins.—white coat on exposed side began checking; this continued, with some curling, for first 50 mins. of test; none of the plaster fell off. 40 to 45 mins.—horizontal cracks appeared over unexposed-side mortar joints at mid height of wall. 1 hr. 30 mins.—fire shut off. (Temperature curves in fig. 88.)

After cooling.—No fire effects were noted on the unexposed side other than fine cracks over horizontal mortar joints. White coat of plaster on exposed side checked and curled. All of exposed plaster calcined and easily removed.

About 12 per cent of the units were in good condition or contained only minor cracks. The remainder of the units had cracks in the webs holding the exposed shells, but only two of the shells were loose. No cracks were found in or beyond the center longitudinal web. (Condition similar to that of wall 59, shown in fig. 30.)

TEST No. 50.—4 by 4 ft.; 8-in. wall plastered on both sides with two coats of 1:3 lime plaster and finished with white coat; restrained; 6-cell 8 by 12 by 11 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—½ min.—buckling of finish and second coat of plaster near middle of exposed surface. 2 mins.—about 2 sq. ft. of plaster fell off. 5 mins.—more exposed plaster fell off. 11 mins.—plaster from 80 per cent of exposed side now off. 20 mins.—spalling on 2 to 3 sq. ft. of exposed surface of tile. 30 mins.—only a little additional spalling; nearly all plaster now off. 24 mins. to 1 hr. 15 mins.—fine cracks appear on the unexposed surface, generally following mortar joints. 1 hr. 30 mins.—fire shut off. 1 hr. 30 mins. to 1 hr. 40 mins.—a considerable number of snapping and cracking sounds were heard. (Temperature curves in fig. 88.)

After cooling.—All of the exposed plaster was off. Spalling on 3 to 4 sq. ft. of exposed tile, but this did not extend through shells. Remainder of surface contains numerous cracks. All of the shells were loose, or the webs holding them were cracked so that the shells were easily loosened. The plaster on the unexposed side was cracked and could be readily removed. (Condition of exposed side shown in fig. 29.)

TEST No. 51.—4 by 4 ft.; 8-in. wall plastered on exposed side with two coats of cement-lime plaster of proportion 1:½:4; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—25 mins.—steam coming from wall and condensing on the unexposed surface. 1 hr. 30 mins.—fire shut off. No fire effects were noted. (Temperature curves in fig. 89.)

After cooling.—All plaster in place, but seems loose in spots. About 25 per cent of the exposed shells were loose; the webs holding the exposed shells of 50 per cent of the units were cracked, but no cracks were found in or beyond the center longitudinal web. (Condition shown in fig. 29.)

TEST No. 52.—4 by 4 ft.; 8-in. wall plastered on the exposed side with two coats of cement-lime plaster of proportion 1:1:5; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—25 mins.—some snapping sounds were heard. 1 hr. 30 mins.—fire shut off. No fire effects on unexposed side were noted. (Temperature curves in fig. 89.)

After cooling.—All of the plaster on the exposed side was in place but was dehydrated and covered with cracks which generally outlined the unit. Approximately 15 per cent of the exposed shells were loose; the webs holding 25 per cent of the exposed shells were cracked; and 60 per cent of the units were in good condition, some of them containing minor surface cracks. (Condition shown in fig. 29.)

TEST No. 53.—4 by 4 ft.; 8-in. wall plastered on the exposed side with two coats of cement-line plaster of proportion 1:2:7; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—3 mins.—very small blisters were formed on the surface of the exposed plaster. 30 mins.—steam coming from the top of the unexposed side of the wall. 1 hr. 30 mins.—fire shut off. No important fire effects were noted. (Temperature curves in fig. 89.)

After cooling.—No fire effects on unexposed side were noted. About 4 sq. ft. of the plaster at the top of exposed side was off. The remainder of the plaster was in place but easily removed. The plaster surface was different from that of the gypsum plaster in that it was not covered with shrinkage cracks. No

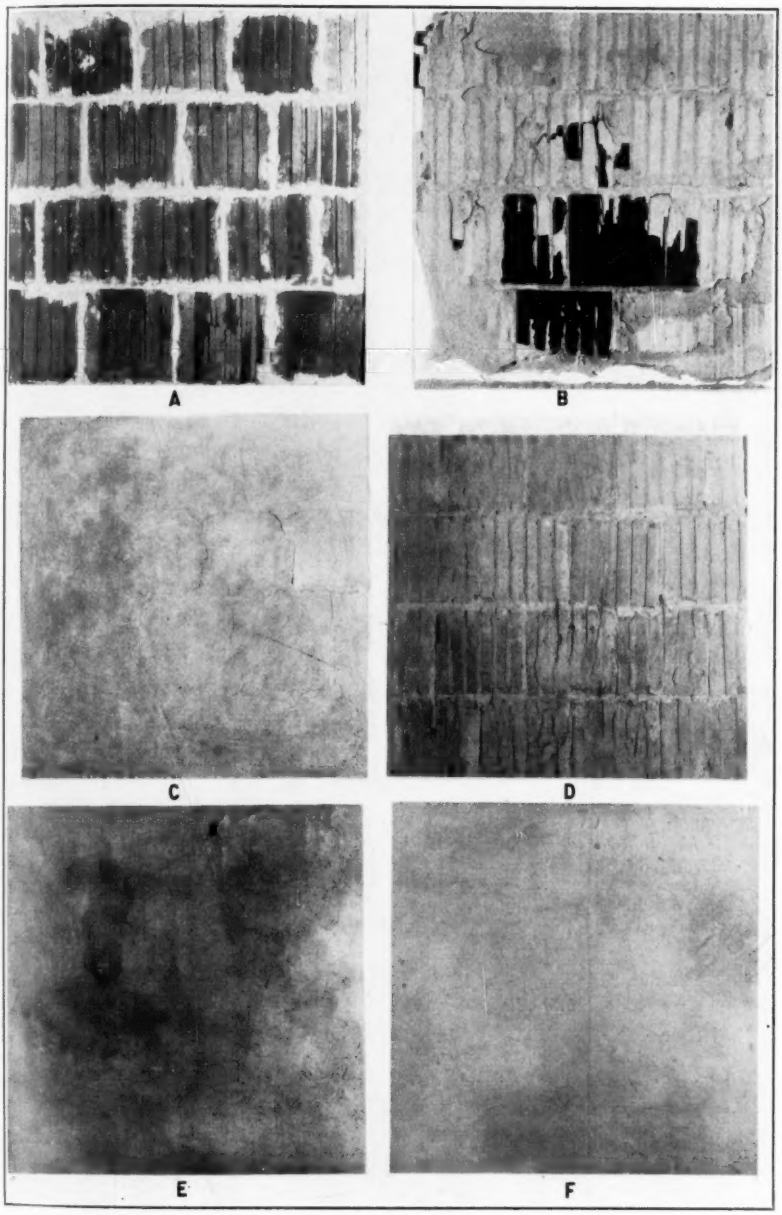


FIG. 29

A, exposed side of wall No. 47 after fire exposure of 1 hour 30 minutes
B, exposed side of wall No. 50 after fire exposure of 1 hour 30 minutes
C, exposed side of wall No. 48 after fire exposure of 1 hour 30 minutes
D, exposed side of wall No. 48 after removing plaster
E, exposed side of wall No. 51 after fire exposure of 1 hour 30 minutes
F, exposed side of wall No. 52 after fire exposure of 1 hour 30 minutes

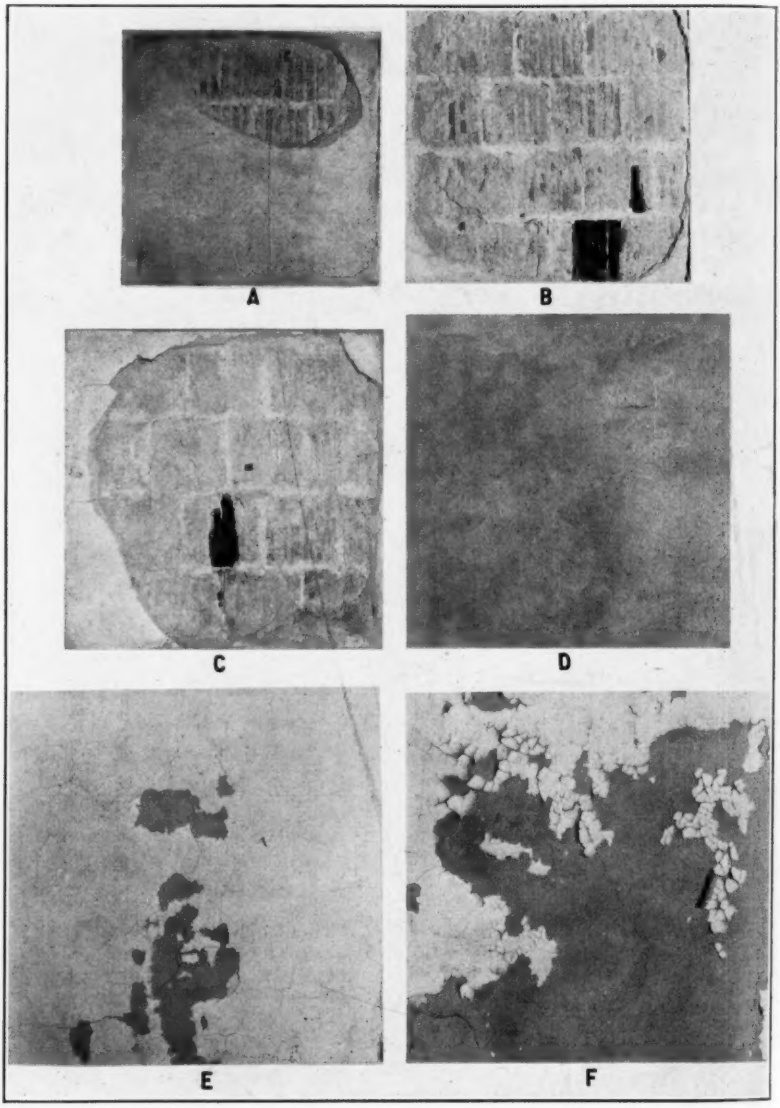


FIG. 30

A, exposed side of wall No. 53 after fire exposure of 1 hour 30 minutes
B, exposed side of wall No. 54 after fire exposure of 1 hour 30 minutes
C, exposed side of wall No. 55 after fire exposure of 1 hour 30 minutes
D, exposed side of wall No. 56 after fire exposure of 1 hour 30 minutes
E, exposed side of wall No. 58 after fire exposure of 1 hour 30 minutes
F, exposed side of wall No. 59 after fire exposure of 1 hour 30 minutes

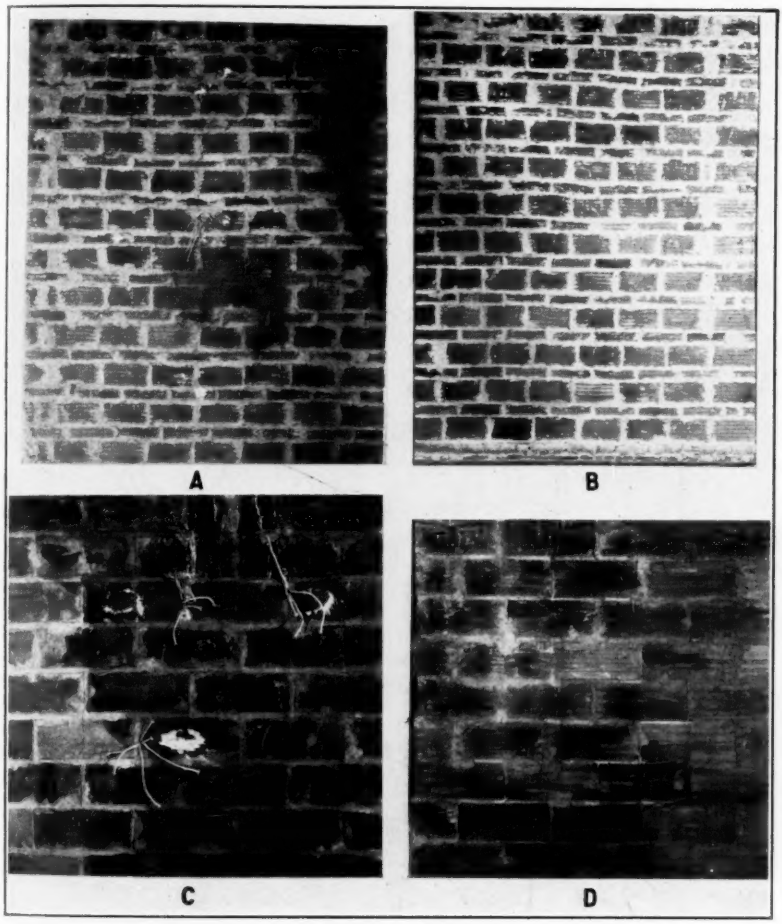


FIG. 31

A, unexposed side of wall No. 60 after fire exposure of 4 hours 25 minutes
B, exposed side of wall No. 60 after fire exposure of 4 hours 25 minutes
C, unexposed side of wall No. 61 after fire exposure of 3 hours 21 minutes
D, exposed side of wall No. 61 after fire exposure of 3 hours 21 minutes

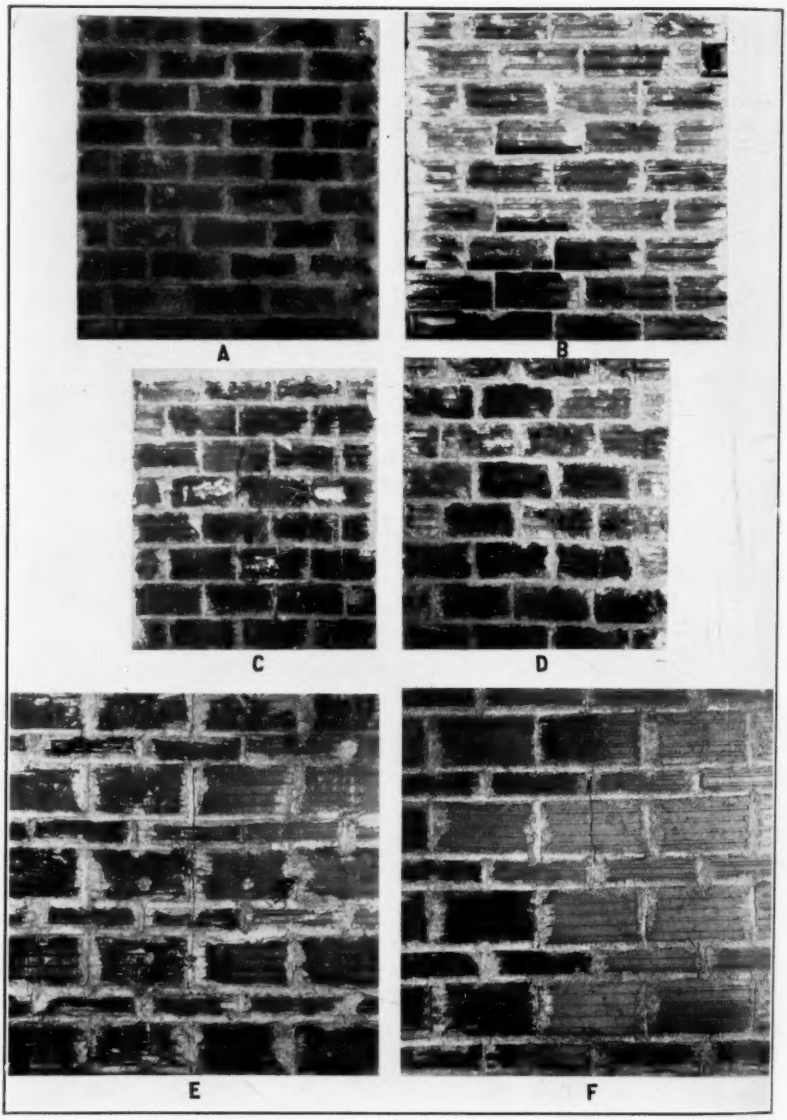


FIG. 32

A, exposed side of wall No. 62 after fire exposure of 2 hours 22 minutes
B, exposed side of wall No. 63 after fire exposure of 1 hour 38 minutes
C, unexposed side of wall No. 64 after fire exposure of 2 hours 42 minutes
D, exposed side of wall No. 64 after fire exposure of 2 hours 42 minutes
E, unexposed side of wall No. 65 after fire exposure of 6 hours
F, exposed side of wall No. 65 after fire exposure of 6 hours

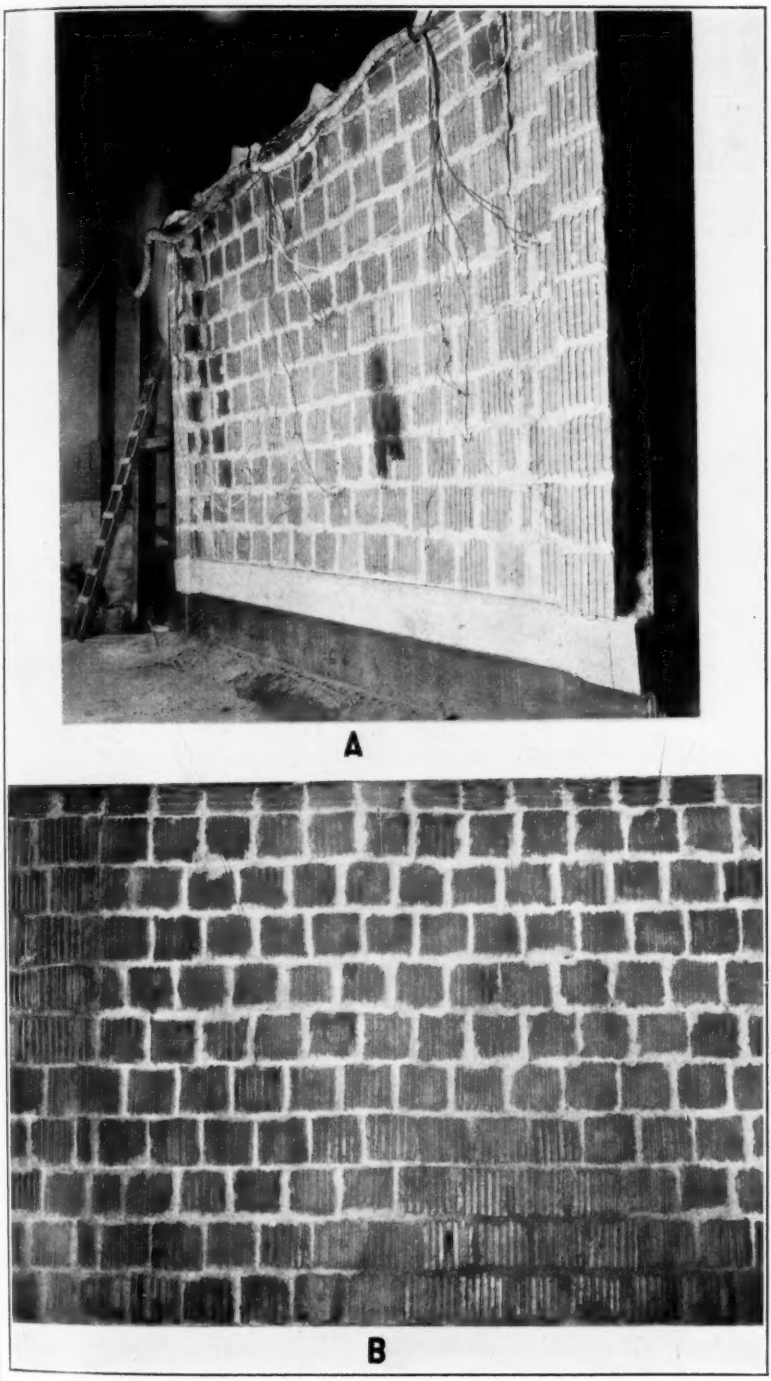


FIG. 33

A, unexposed side of wall No. 67 at the end of fire exposure of 6 hours
B, exposed side of wall No. 67 after fire exposure of 6 hours

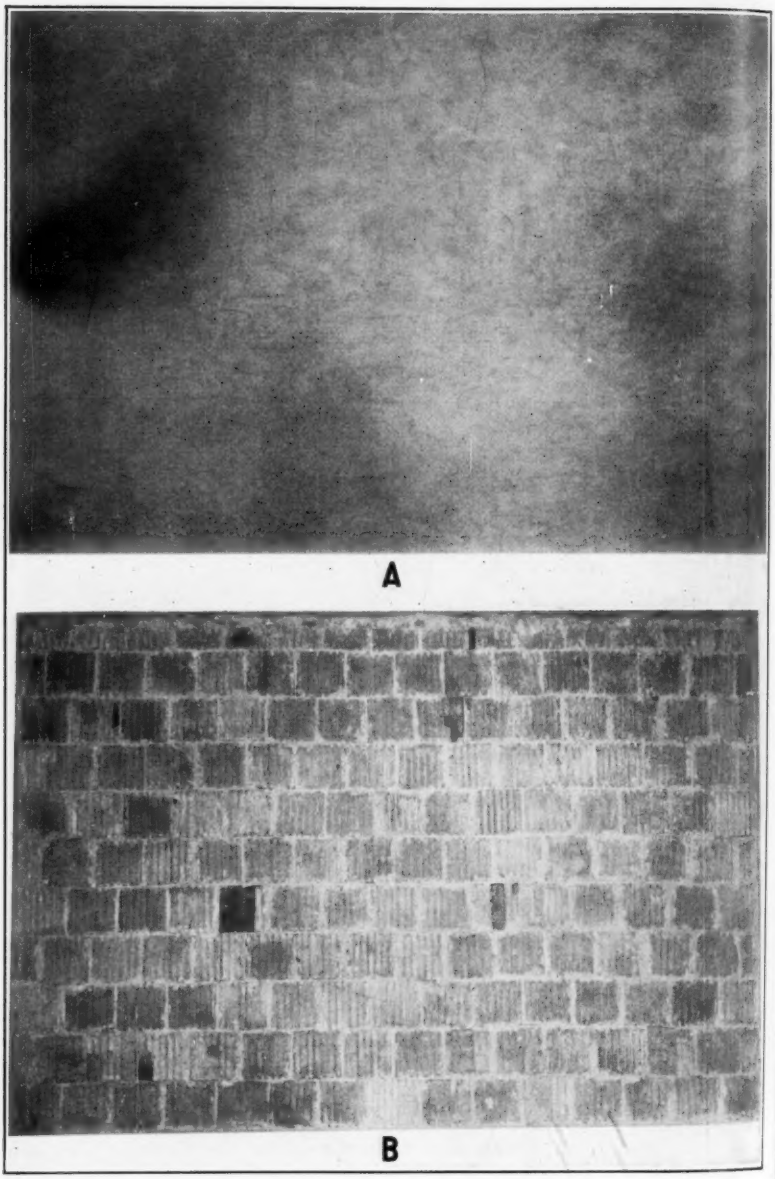


FIG. 34

A, exposed side of wall No. 68 after fire exposure of 6 hours
B, exposed side of wall No. 68 after removal of plaster

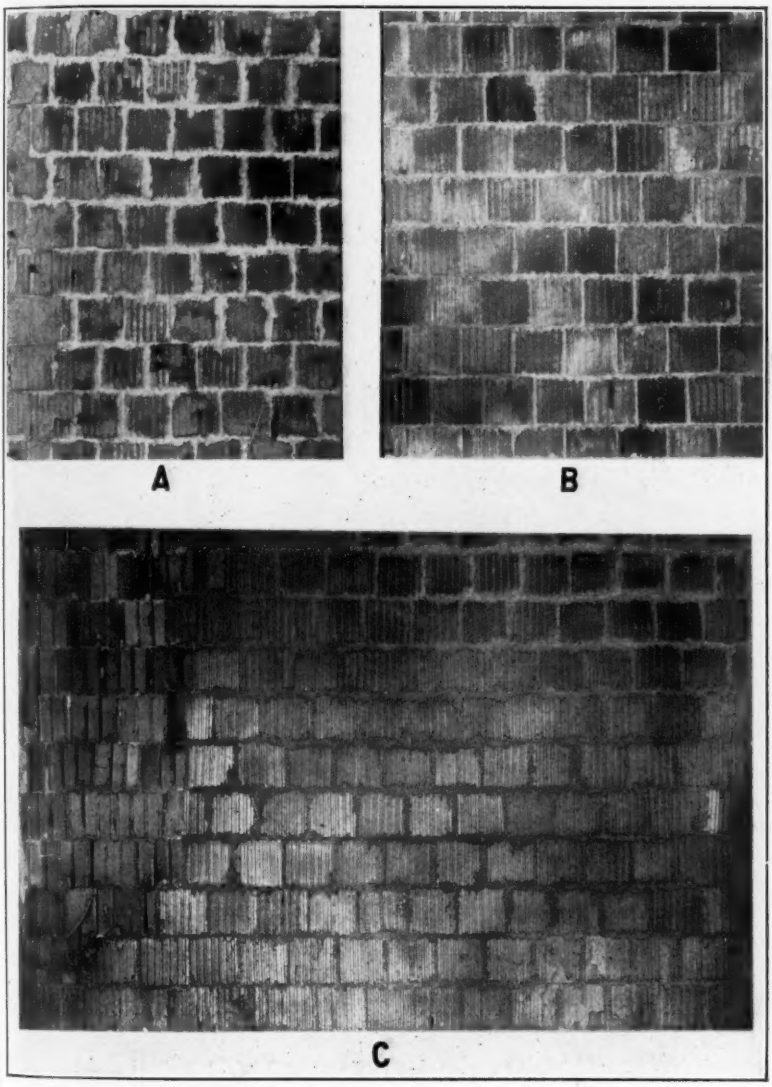


FIG. 35

A, exposed side of wall No. 69 after fire exposure of 6 hours
B, exposed side of wall No. 74 after fire exposure of 3 hours
C, exposed side of wall No. 76 after fire exposure of 6 hours

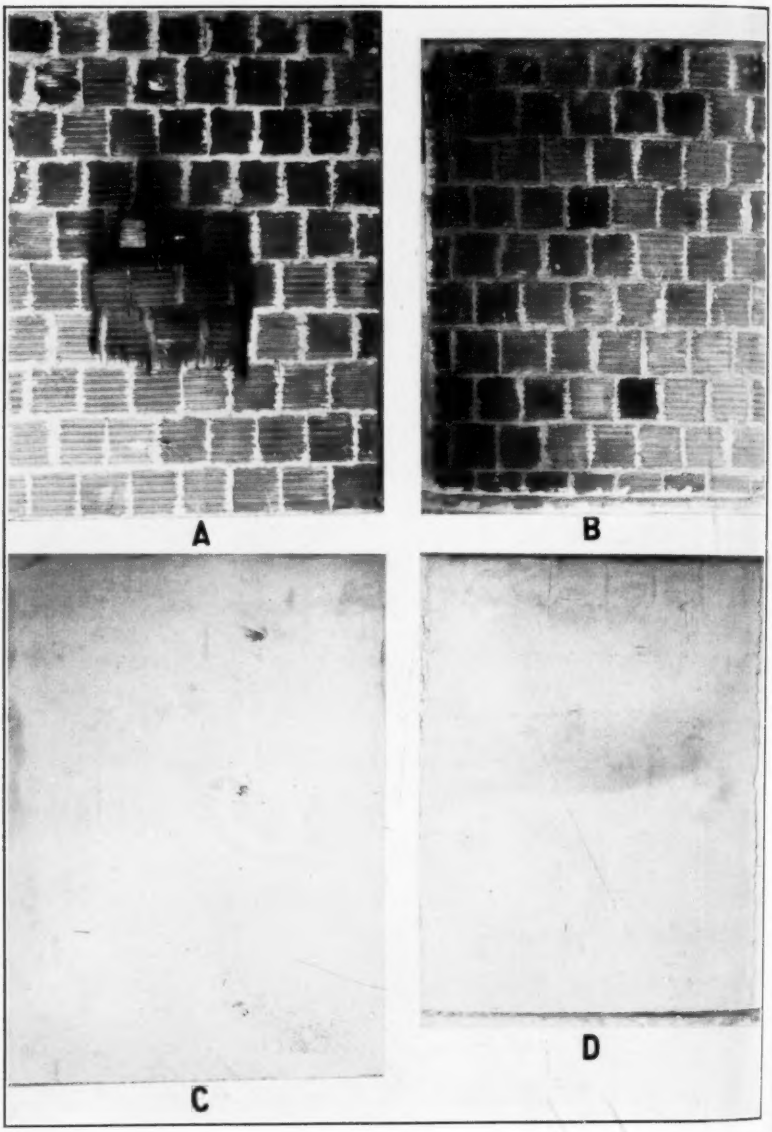


FIG. 36

A, unexposed side of wall No. 79 after fire exposure of 2 hours
B, exposed side of wall No. 79 after fire exposure of 2 hours
C, unexposed side of wall No. 80 after fire exposure of 2 hours
D, exposed side of wall No. 80 after fire exposure of 2 hours

examination of the condition of the units in this wall was made. (Condition shown in fig. 30.)

TEST No. 54.—4 by 4 ft.; 8-in. wall plastered on exposed side with two coats of lime plaster of 1:3 proportion; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—4 mins.—second coat and part of first coat of plaster on lower half of exposed side fell off. 6½ to 12 mins.—most of the rest of the plaster fell off. 45 mins.—part of the ridges on two exposed shells near bottom of wall spalled. 50 mins.—snapping and cracking sounds were heard. 1 hr. 5 mins.—steam coming from mortar joints on the unexposed side. 1 hr. 30 mins.—fire shut off. (Temperature curves in fig. 89.)

After cooling.—No fire effects on unexposed side were noted. All of the plaster was off. All of the exposed shells were in place, but they were loose, or the webs holding them were cracked so that they could be easily pulled off. (Condition shown in fig. 30.)

TEST No. 55.—4 by 4 ft.; 8-in. wall plastered on exposed side with lime plaster of 1:3 proportion; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—Wall aged 384 days before testing. 11 mins.—about 5 sq. ft. of plaster near middle of exposed side bulging; at 13 mins. this plaster fell off. 15 mins.—about 4 sq. ft. of plaster near middle of exposed side fell off. 53 mins.—remainder of plaster, except portions along edges, now off. 23 to 28 mins.—spalling on exposed surface of several tile near center of wall. 1 hr. 30 mins.—fire shut off. (Temperature curves in fig. 89.)

After cooling.—No fire effects on unexposed side were noted. All of the exposed plaster was off, except near the edges. The exposed surface of one unit near middle of wall was spalled to a depth of ¼ inch. Although all exposed shells were in place, about 25 per cent of them were loose, and the webs holding the remainder of them were cracked. No cracks were found in or beyond the center longitudinal web. (Condition shown in fig. 30.)

TEST No. 56.—4 by 4 ft.; 8-in wall plastered on the exposed side with one coat of cement plaster of 1:2½ volume proportions; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from course *k*. (Type 8–B–E fig. 12a.)—10 mins.—some snapping. Cracks in plaster in upper east portion of wall. 14 to 20 mins.—further cracking of plaster at two places near the middle of the wall. 40 mins.—steam coming from mortar joints on unexposed side of wall. 1 hr.—crack forming in horizontal unexposed mortar joint at mid height of wall. 1 hr. 30 mins.—fire shut off. (Temperature curves in fig. 90.)

After cooling.—All of the plaster on the exposed side was in place, but it was covered with cracks which, in general, outlined the units. It was not difficult to remove the plaster. Although all of the shells were in place, about half of them were loose, and the webs holding the remainder of them were cracked so that the shells could be easily pulled off. (Condition shown in fig. 30.)

TEST No. 57.—4 by 4 ft.; 8-in. wall plastered on the exposed side with two coats of cement plaster of 1:3 proportion tempered with 15 per cent addition of lime; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—3 to 10 mins.—numerous small spalls on the exposed surface of the plaster. 1 hr. 30 mins.—no further fire effects were noted. Fire shut off. (Temperature curves in fig. 90.)

After cooling.—No fire effects on unexposed side were noted. All of the plaster on the exposed side was in place, except small spall over about 6 sq. in. The second coat of plaster could be removed, but the first coat could not without breaking the tile. (Condition similar to that of wall 56, shown in fig. 30.)

TEST No. 58.—4 by 4 ft.; 8-in. wall plastered on exposed side with one coat of 1:3 gypsum plaster and a white finish coat; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—15 mins.—white finish coat of plaster peeling. 25 mins.—snapping and cracking sounds were heard. 1 hr. 30 mins.—fire shut off. (Temperature curves in fig. 90.)

After cooling.—No fire effects on unexposed side were noted. About 1½ sq. ft. of finish coast of plaster on exposed side was off. The remainder of finish coat was covered with a network of fine cracks. About 50 per cent of the units had the webs holding their exposed shells cracked. The remainder of the units were in good condition or contained only minor cracks. (Condition shown in fig. 30.)

TEST No. 59.—4 by 4 ft.; 8-in. wall plastered on exposed side with two coats of 1:3 gypsum plaster and a white finish coat; restrained; 6-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 8–B–E, fig. 12a.)—1 min.—finish coat on exposed side began to crack and curl. 18 mins.—75 per cent of the finish coat peeling. 1 hr. 10 mins.—a fine crack formed in the unexposed side horizontal mortar joint at mid height of wall. 1 hr. 30 mins.—fire shut off. (Temperature curves in fig. 90.)

After cooling.—75 per cent of the white finish coat of plaster was off. The remainder of the plaster was in place, but it contained cracks which generally outlined the units. Only one exposed shell was loose; two tiles had webs cracked, the remainder of the units being in good condition or containing only minor cracks. (Condition shown in fig. 30.)

TEST No. 60.—8 by 10⅓ ft.; 8-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *p*–1. (Type 8–O–S, fig. 12b)—12 to 45 mins.—two vertical cracks, extending from the top to the bottom of wall along vertical mortar joints and across intervening units, appeared near the middle of unexposed side of the wall. 40 mins.—steam coming from mortar joints, increasing in amount as test proceeded. 2 hrs. 30 mins.—steaming ceased. 3 hrs. 35 mins.—cotton pad was removed; the cotton was charred and glowing in several places but did not blaze. 4 hrs. 25 mins.—fire shut off because of shut down of the compressor supplying air for the burners. This test was continued 1 hr. 22 mins. beyond the resistance period of the wall. The load was increased to 120 lbs./in.² No cracking sounds heard. (Temperature curves in fig. 91.)

After cooling.—A load of 80 lbs./in.² was applied, with considerable cracking. No overload was applied. All of the exposed shells were in place. About 50 per cent of the units had loose shells or cracks in the webs holding them. In addition to this, a large percentage of the tile contained vertical cracks usually extending through the wall and breaking the unit into two 6-in. lengths. A masonry specimen taken from this wall and tested in compression failed under a load of 110 lbs./in.² (Condition shown in fig. 31.)

TEST No. 61.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; 3-cell 8 by 5 by 12 in. side-construction surface-clay tile from source *o–1*. (Type 8–K–S, fig. 12b)—2 mins.—spalling on the exposed surface of several of the tile started, mostly at bottom; this spalling was continuous throughout the test; at one place it extended through the exposed shell. 12 to 17 mins.—cracks up to ½ in. wide, dividing units into two 6-in. lengths, appeared on unexposed surface. 3 hrs. 21 mins.—fire shut off, as the resistance period of the wall, as determined by the temperature rise, was reached at 2 hrs. 49 mins. 3 hrs. 24 mins.—load increased to 120 lbs./in.² No snapping or cracking sounds heard during the application of the load. (Temperature curves in fig. 92.)

After cooling.—Carried load of 120 lbs./in.² No snapping or cracking sounds were heard during the application of the load. Spalling over about 25 per cent of the exposed surface extended through the exposed shells at one place over an

area of 6 by 6 in. Although the exposed shells were in place, all of them were loose, the cracks in many units penetrating into and beyond the first longitudinal web parallel to the exposed surface. In addition, the majority of the units were divided into two lengths by vertical cracks in line with the vertical mortar joints in adjacent courses. (Condition shown in fig. 31.)

TEST No. 62.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; 2-cell 8 by 5 by 12 in. side-construction surface-clay tile from source *k–1*. (Type 8–L–S)—35 mins.—a vertical crack starting from top middle of unexposed surface. At 1 hr. 40 mins. crack noted above has now extended to within 16 in. of bottom of wall by following mortar joints and breaking across units. 2 hrs. 15 mins.—a few vertical cracks through units on unexposed surface. 1 hr.—steam from imperfect mortar joints. 2 hrs. 22 mins.—fire shut off, as the resistance period, as determined by the temperature rise on the unexposed surface, was obtained at 1 hr. 48 mins. 2 hrs. 26 mins.—load increased to 120 lbs./in.² without cracking sounds being heard. (Temperature curves in fig. 92.)

After cooling.—Loads of 80 and 120 lbs./in.² were carried. No cracking sounds were heard during the application of the load of 80 lbs./in.², but when the load was increased to 120 lbs./in.² a number were heard. All of the exposed shells were in place, but the webs holding them were cracked so that the shells could be easily loosened. Except for vertical cracks dividing a few of the units into two lengths, there were no cracks in or beyond the center longitudinal web. (Condition shown in fig. 32.)

TEST No. 63.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; 2-cell 8 by 5 by 12 in. side-construction surface-clay tile from source *k–3*. (Type 8–L–S)—2 mins.—many cracking sounds heard. 6 mins.—spalling of ridges on the exposed surface, mostly in lower part of wall. 7 to 50 mins.—vertical cracks forming on the unexposed surface. 1 hr. 38 mins.—fire shut off, as the temperature limit on the unexposed side was thought to have been obtained. 1 hr. 42 mins.—load of 120 lbs./in.² was applied. (Temperature curves in fig. 93.)

After cooling.—Load of 80 lbs./in.² carried, but cracking sounds were heard during the application of the load. All of the exposed shells were in place, but they were spalled or contained one or more cracks. The webs holding the exposed shells of all of the units were cracked, but generally the damage did not extend beyond the center longitudinal web. (Condition shown in fig. 32.)

TEST No. 64.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; 6-cell 8 by 6 by 12 in. side-construction surface-clay tile from source *k–2*. (Type 8–U–S.)—8 mins. to 1 hr. 55 mins.—vertical cracks appeared on the unexposed side under vertical mortar joints between superimposed tile. 2 hrs. 42 mins.—fire shut off, as the temperature limit on the unexposed side was thought to have been obtained. (Temperature curves in fig. 93.)

After cooling.—Load of 80 lbs./in.² was applied. Overload was not applied. No fire effects on unexposed side, except vertical cracks, were noted. Small spalls to depth of scoring had fallen from many exposed shells. All of the exposed shells were in place, but 70 per cent of them were loose. The webs holding the remainder of the shells were cracked. With the exception of the vertical cracks previously noted, no cracks were found in or beyond the first longitudinal web. (Condition shown in fig. 32.)

TEST No. 65.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *r*. (Type 8–O–S, fig. 12b.)—11 mins.—snapping sounds were heard. 14 mins. to 3 hrs. 40 mins.—vertical cracks appeared on the unexposed shells of a number of the units, mostly near the center of the wall. 1 hr.—steam coming from mortar joints. Fire shut off at 6 hrs., which was 3 hrs. 58 mins. beyond the resistance period of the wall. (Temperature curves in fig. 94.)

After cooling.—Although all of the exposed shells were in place, the webs holding them were cracked so that they were loose or could be easily pulled away. The most prominent cracks were vertical, extending across the face of the units and through the wall, dividing the units into two equal lengths. The shells of a number of the units were damaged beyond the first longitudinal web. (Condition shown in fig. 32.)

TEST No. 66.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *r*. (Type 8–O–S, fig. 12b.)—9 mins.—cracking sounds were heard. 20 mins.—two loud cracking sounds were heard. 22 and 40 mins.—vertical cracks appeared on the unexposed shells of two units. 22 mins.—steam coming from mortar joints. 45 mins.—fire shut off to determine the effect of short exposures. 45 to 48 mins.—cracking sounds were heard. (Temperature curves in fig. 94.)

After cooling.—No damage on the unexposed side was observed, other than the vertical cracks noted above. Although all the exposed shells were in place, vertical cracks were found in 90 per cent of the exposed shells, about one-fourth of which extended through the tile, breaking it into two equal lengths. About 30 per cent of the exposed shells were loose. The webs holding 10 per cent of the exposed shells were cracked, but the shells were not loose; 20 per cent of the units were in good condition or contained only minor cracks. (Condition similar to wall 65, shown in fig. 32.)

TEST No. 67.—16 by 11 ft.; 8-in. wall unplastered; unrestrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *n*. (Type 8–A–E, fig. 12a.)—1½ mins.—first snapping sounds were heard. 5 mins.—a crack at top near south end extended downward along mortar joints; this crack opened at top to about ½ in. at 10 mins. 9 mins.—a crack started at top about 5 ft. from north end and extended downward along mortar joints to bottom of wall. 16 mins.—crack started at top about 2 ft. from north end, extended downward three courses along mortar joints. 1 hr. 8 mins.—a number of spalls from exposed shells in lower part of wall. 2 hrs. 40 mins.—smoke coming from cotton pad. 3 hrs.—cotton pad removed, flaming. 3 hrs. 8 mins.—smoke from excelsior-filled box. 4 hrs. 13 mins.—excelsior-filled box blazing. Fire was turned off at 6 hrs., which was 3 hrs. 37 mins. beyond the resistance of the wall. The crack noted at 9 mins. was $\frac{1}{16}$ in. wide at top and the one noted at 5 mins. ½ in. at top. (Temperature curves shown in fig. 95.)

After cooling.—None of the exposed shells were off, although 34 per cent of them were loose. The webs holding 51 per cent of the shells were cracked so that they were easily loosened; 5 per cent of the units were practically free from damage. A masonry specimen taken from this wall and tested in compression failed under a load of 250 lbs./in.² (Condition shown in fig. 33.)

TEST No. 68.—16 by 11 ft.; 8-in. wall plastered on both sides with gypsum plaster; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *n* (Type 8–A–E, fig. 12a.)—21 mins.—first snapping sounds were heard. 45 mins.—steam coming from wall and condensing on the unexposed surface. 1 hr.—horizontal crack at bottom of wall formed and opened about $\frac{1}{16}$ in. 4 hrs. 45 mins.—occasional cracking sounds. 5 hrs. 30 mins.—smoke coming from excelsior-filled box. 6 hrs. 25 minutes.—smoke coming from cotton pad; excelsior-filled box blazing. 6 hrs. 38 mins.—cotton pad blazing. Fire shut off at 6 hrs., which was 1 hr. 25 mins. beyond the fire-resistance period of the wall. (Temperature curves in fig. 96.)

After cooling.—The plaster on the exposed side was in place but was calcined and filled with many shrinkage cracks. In removing the plaster from the exposed side, small spalls came off a few tile. The webs holding the exposed shells of 53 per cent of the units were cracked so that the shells could be easily

pulled off. The webs holding 37 per cent of them were cracked, but the shells were not loose; 10 per cent of the units were in good condition. Three units were damaged beyond the center longitudinal web. A masonry specimen taken from the wall and tested in compression failed under load of 320 lbs./in.² (Condition shown in fig. 34.)

TEST No. 69.—8 by 10⅓ ft.; 8-in. wall unplastered; 120 lbs./in.² load. 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *n*. (Type 8–A–E, fig. 12a.)—3½ to 10 mins.—many cracking sounds were heard. 10 to 20 mins.—spalling of ridges of exposed surface, mostly in lower two-thirds of wall. 30 mins.—three vertical cracks appeared on the unexposed side. 37 mins. to 4 hrs. 30 mins.—steaming and condensation on unexposed side. 3 hrs. 20 mins.—cotton pad burning. Fire shut off at 6 hrs., which was 3 hrs. 43 mins. beyond the resistance period of the wall. (Temperature curves in fig. 97.)

After cooling.—A load of 120 lbs./ in.² was applied, but many cracking sounds were heard, indicating that this was near the ultimate strength of the wall. Many of the ridges on the exposed surface were spalled. All of the exposed shells were in place but were loose. Masonry specimens were not taken from this wall for compression tests. (Condition shown in fig. 35.)

TEST No. 70.—8 by 10⅓ ft.; 8-in. wall plastered on both sides with gypsum plaster; 120 lbs./ in.² load; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *n*. (Type 8–A–E, fig. 12a.)—15 mins.—a fine vertical crack appeared on the unexposed surface near the top and 2 ft. from the end of the wall. 4 hrs. 30 mins.—a vertical crack appeared on the unexposed surface near the mid height and about 2 ft. from one end. 5 hrs. 30 mins.—crack noted at 4 hrs. 30 mins. was opened about $\frac{3}{32}$ in. 52 mins.—first condensation noted on plaster on unexposed side. 1 hr. 15 mins.—condensation noted at many points on plaster on unexposed side. 5 hrs. 55 mins.—smoke coming from cotton pad. 5 hrs. 58 mins.—cotton pad removed; the cotton in contact with the wall was glowing but did not flame. The fire was shut off at 6 hrs., which was 1 hr. 23 mins. beyond the fire-resistance period of the wall. (Temperature curves in fig. 98.)

After cooling.—A load of 120 lbs./in.² was applied, with only a few snapping sounds. All of the plaster on the exposed side was in place but was calcined and easily removed. Although all of the exposed shells were in place, 50 per cent of them were loose. The webs holding 30 per cent of the exposed shells were cracked, but the shells were not loose; 20 per cent of the units were in good condition or contained only minor cracks. A masonry specimen for compression tests was not taken from this wall. (Condition of exposed plaster similar to wall 68, shown in fig. 34.)

TEST No. 71.—8 by 11 ft.; 8-in. wall unplastered; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *n*. (Type 8–A–E, fig. 12a.)—[illegible] to 12 mins.—cracking sounds were heard, mostly from spalling of ridges on the exposed side of wall. 45 mins.—steam coming from imperfect mortar joints. [illegible]0 mins.—a crack on unexposed side started in lower horizontal mortar joints. [illegible] hr. 40 mins.—Fire shut off, as the resistance period on the companion wall had been passed. This was 2 hrs. 38 mins. beyond the resistance period of the wall. (Temperature curves in fig. 99.)

After cooling.—The exposed shells were spalled decidedly on some tile for one-half of shell thickness. Although no exposed shells were off, 70 per cent of them were loose, and the webs holding the remainder were cracked. No cracks were found in or beyond the center longitudinal web. A masonry specimen cut from this wall failed under a load of 280 lbs./in.² (Condition similar to that of wall 69, fig. 35.)

TEST No. 72.—8 by 11 ft.; 8-in. wall plastered on both sides with gypsum plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *n*. (Type 8–A–E, fig. 12a.)—1 hr.—wet spots appearing on the unexposed surface. 2 hrs. 35 mins.—fine crack formed in one horizontal mortar joint. 4 hrs. 40 mins.—fire shut off, as the resistance period, as determined by the temperature rise on the unexposed surface, was obtained at 4 hrs. 28 mins. (Temperature curves in fig. 100.)

After cooling.—About 3½ sq. ft. of plaster near the edges of the exposed side were off; 6 per cent of the exposed shells were loose; some of the webs holding 22 per cent of the exposed shells were cracked; 72 per cent of the units were in good condition. A masonry specimen cut from this wall failed under a load of 410 lbs./in.² (Condition similar to that of wall 68, fig. 34.)

TEST No. 73.—4 by 4 ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*. (Type 8–A–E, fig. 12a.)—5 to 12 mins.—faint cracking sounds were heard. 1 hr.—no effects on fire side visible, except small spall on tile near panel edge. 18 mins. to 2 hrs. 20 mins.—fine vertical cracks appeared in unexposed shells of some tile. Fire shut off at 6 hrs., which was 4 hrs. 33 mins. beyond the resistance period of the wall. (Temperature curves in fig. 101.)

After cooling.—Wall carried load of 120 lbs./in.² All of the exposed shells were in place, but the webs holding them were cracked so that about 75 per cent of the shells were loose. The other units contained cracks, but the shells were not loosened. (Condition similar to that of wall 83, fig. 37.)

TEST No. 73A.—4 by 4 ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*. (Type 8–A–E, fig. 12a.)—(This wall was dried to near constant weight before being tested.) 18 mins. to 1 hr.—small amount of steam coming from imperfect mortar joints near top of wall. 1 hr. 26 mins.—fire shut off, as the resistance period of the wall was obtained at 1 hr. 25 mins. An overload was not applied. (Temperature curves in fig. 154.)

After cooling.—The load was not applied. No fire effects were noted on unexposed surface of the wall. Four of the exposed shells were off. The webs holding the remainder of the exposed shells were cracked so that the shells were loose. The cracks in the webs did not extend beyond the center longitudinal web.

TEST No. 74.—8 by 10⅓ ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*, set in cement mortar. (Type 8–A–E, fig. 12a.)—4 mins.—some snapping sounds heard. 20 mins.—a vertical crack appeared near the middle of the wall, extending from the top to the bottom on the unexposed side and following the vertical mortar joints and breaking across intervening tiles. 2 hrs.—a vertical crack about 4 ft. long appeared near the bottom of the north end on unexposed side of the wall. 27 mins.—steam coming from imperfect mortar joints. 2 hrs.—no further steam coming from the wall. 2 hrs. 10 mins.—smoke coming from excelsior-filled box. 2 hrs. 31 mins.—box blazed and was removed. Fire was shut off at 3 hrs. 1 min., which was 1 hr. 30 mins. beyond the resistance period of the wall. The load was increased to 157 lbs./in.² without cracking sounds from wall. (Temperature curves in fig. 102.)

After cooling.—A load of 120 lbs./in.² was applied, with only small number of cracking sounds from wall. Although none of the exposed shells were off, about 60 per cent of them contained vertical cracks; 63 per cent of the exposed shells were loose. The webs holding the exposed shells of 37 per cent of the units were cracked, but the shells were not loose; 5 per cent of the units contained cracks beyond the longitudinal web. Although the difference is small, this was

was in a little better condition than wall 75, for which cement-lime mortar was used. A masonry specimen was not taken from this wall. (Condition shown in fig. 35.)

TEST No. 75.—8 by 10⅓ ft.; 8-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l* set in cement-lime mortar. (Type 8–A–E, fig. 12a)—4 mins.—many snapping sounds were heard. 5 mins.—loud cracking sounds were heard. 8 mins.—small spalls coming from the bottom middle of the exposed side of the wall. 17 mins.—a vertical crack formed 2 ft. from the south end, extending from top to bottom of the wall on unexposed side, following vertical mortar joints, and breaking through intervening units. 30 mins.—crack noted at 17 mins. now opened about $\frac{1}{16}$ in. An additional vertical crack appeared near center of the wall. 50 mins.—a vertical crack about 4 ft. long appeared 6 in. from the south end on unexposed side, extending upward from the bottom of the wall. 25 mins.—steam coming from cracks. 1 hr.—a large amount of steam now coming from the wall. 2 hrs.—no further steam from the wall. 2 hrs. 10 mins.—smoke from cotton pad. 2 hrs. 27 min.—cotton pad removed; half of cotton was consumed, the remainder charred, but it did not blaze. Fire shut off at 3 hrs. 1 min., which was 1 hr. 18 mins. beyond the resistance period of the wall. The load was increased to 157 lbs./in.² under which the wall showed signs of approaching failure. (Temperature curves in fig. 102.)

After cooling.—A load of 120 lbs./in.² was applied, this probably being near the ultimate strength of the wall, as indicated by the snapping and cracking sounds. Although none of the exposed shells were off, about 90 per cent of them contained vertical cracks; 82 per cent of the exposed shells were loose. The webs holding the remaining 18 per cent of the exposed shells were cracked, but the shells were not loose. Cracks were found beyond the longitudinal webs of 8 per cent of the units. A masonry specimen was not taken from this wall. (Condition similar to wall 74, shown in fig. 35.)

TEST No. 76.—16 by 11 ft. 8-in. wall unplastered; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*. (Type 8–A–E, fig. 12a)—6½ to 21 mins.—a number of snapping and cracking sounds were heard. 34 mins.—steam coming from mortar joints and condensing on the unexposed surface of the wall. 50 mins.—small spalls from exposed shells of tile in lower north portion of wall. 50 mins.—4 or 5 shells near south center of wall buckled toward the fire 2 to 3 in. 1 hr. 25 mins.—fine crack about 6 ft. long in first horizontal mortar joint above bottom on the unexposed side. 2 hrs. 30 mins.—shells noted at 50 mins. now buckled about 6 in. 3 hrs. 14 mins. to 5 hrs. 53 mins.—these and others in south part of wall fell off. 5 hrs. 43 mins.—the unexposed side mortar joints in the upper south corner of the wall spalled, indicating the fire damage penetrates to near the unexposed side at this point. 2 hrs. mins.—much smoke coming from the cotton pad; a small amount from the excelsior-filled box. 2 hrs. 25 mins.—the cotton pad removed; the cotton was glowing and smoldering but did not blaze. 2 hrs. 43 mins.—the excelsior-filled box blazed and was removed. Fire shut off at 6 hrs., which was 4 hrs. 8 mins. beyond the resistance period of the wall. (Temperature curves in fig. 103.)

After cooling.—27 per cent of the exposed shells had fallen off, and 67 per cent were loose. The webs holding the remaining 6 per cent of the exposed shells were cracked, but the shells were not loose. Cracks were found beyond the longitudinal webs of 27 per cent of the units, so that the unexposed shells were also loosened. A masonry specimen taken from this wall and tested in compression failed under a load of 215 lbs./in.² (Condition shown in fig. 35.)

TEST No. 77.—8 by 11 ft.; 8-in. wall plastered on exposed side with gypsum plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from

source *l*. (Type 8–A–E, fig. 12a)—7 mins.—approximately 25 per cent of the second coat of the plaster fell off, but all of the first coat remained in place. 30 mins.—steam coming from mortar joints at top of wall. 2 hrs.—no further steam from wall. 3 hrs. 30 mins.—smoke coming from the excelsior-filled box. 3 hrs. 45 mins.—box was removed; it did not blaze, but it was charred over an imperfect mortar joint. Fire shut off at 5 hrs. 42 mins., which was 3 hrs. 1 min. beyond the fire-resistance period of the wall, as determined by the temperature rise on the unexposed surface. (Temperature curves in fig. 104.) (It was necessary to combine these curves with those of test 78, due to the arrangement of the thermocouples.)

After cooling.—About 25 per cent of the second coat of plaster had fallen off; 20 per cent of the exposed shells were loose; the webs holding the exposed shells of 22 per cent of the units were cracked, but the shells were not loose, and 58 per cent of the units were in good condition. A masonry specimen taken from the wall and tested in compression failed under a load of 395 lbs./in.² (Condition similar to wall 80, shown in fig. 36.)

Test No. 78.—8 by 11 ft.; 8-in. wall plastered on the exposed side with cement plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*. (Type 8–A–E, fig. 12a.)—30 mins.—steam from imperfect mortar joints near top of unexposed side. 2 hrs.—only a small amount of steam from wall. 3 hrs. 2 mins.—smoke coming from cotton pad. 3 hrs. 16 mins.—pad was removed, a small amount of the cotton was consumed, the remainder being charred but did not blaze. Fire shut off at 5 hrs. 42 mins., which was 3 hrs. 1 min. beyond the fire-resistance period of the wall. (It was necessary to combine the temperature curves of this wall (fig. 104) with those of test No. 77, due to the arrangement of the thermocouples.)

After cooling.—The only apparent damage to this wall consisted of shrinkage cracks in the exposed plaster, generally outlining the tile units. However, in dismantling, it was found that 24 per cent of the exposed shells were loose; that the webs holding the exposed shells of 15 per cent of the units were cracked, but the shells were not loose; 61 per cent of the units were in good condition. A masonry specimen cut from this wall and tested in compression failed under a load of 180 lbs./in.² (Condition of exposed plaster similar to that of wall 58, shown in fig. 30.)

Test No. 79.—8 by 10⅛ ft.; 8-in. wall unplastered; 80 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*, laid on side. (Type 8–A–S.)—4 to 10 mins.—indistinct snapping sounds were heard. 15 mins.—one fine crack 2 ft. long near bottom of wall. 1 hr. 35 mins.—no moisture steaming from wall. 2 hrs.—fire shut off, as the resistance period of the wall was obtained at 1 hr. 30 mins. Load increased to 120 lbs./in.², with some snapping sounds during application. 2 hrs. 12 mins.—smoke coming from excelsior-filled box. This box burst into flame at 2 hrs. 22 mins. (Temperature curves in fig. 105.)

After cooling.—Wall carried a load of 80 lbs./in.², but failure started near the top when a load of 120 lbs. was applied; 71 per cent of the exposed shells were loose; the webs holding 22 per cent were decidedly cracked; and the remaining 7 per cent were in good condition or contained only minor cracks. Most of the units in top two courses were cracked in or beyond the center longitudinal web. Much of this cracking was probably caused by the overload. A masonry specimen taken from this wall failed under a load of 160 lbs./in.² (Condition shown in fig. 36.)

Test No. 80.—8 by 10⅛ ft.; 8-in. wall plastered on both sides with gypsum plaster; 80 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*, laid on side. (Type 8–A–S.)—No cracks on unexposed side w

noticed during test. 50 mins. to 2 hrs.—condensation of steam in spots on unexposed side. 2 hrs.—fire shut off, as resistance period of companion wall had been obtained. 2 hrs. 5 mins.—load of 120 lbs./in.² carried. The excelsior-filled box on this wall did not ignite. (Temperature curves, fig. 105.)

After cooling.—Wall carried 120 lbs./in.² load. No plaster was off, but cracks on exposed side outlined the tile; 10 per cent of the exposed shells were loose; the webs holding 7 per cent were cracked; and 83 per cent of the units were in good condition. A masonry specimen cut from this wall failed under a load of 265 lbs./in.² (Condition shown in fig. 36.)

TEST No. 81.—8 by 11 ft.; 8-in. wall unplastered; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*, laid on side. (Type 8–A–S.)—10 to 15 mins.—occasional snapping sounds were heard. No cracks were noted during the test. 27 mins. to 1 hr. 50 mins.—steam coming from various places on unexposed side of wall. 1 hr. 15 mins.—joint at bottom center of wall opened slightly, and center of wall slid about $\frac{1}{32}$ in. toward fire. 1 hr. 48 mins.—smoke coming from cotton pad. 2 hrs.—cotton pad removed, lower corner glowing. Fire shut off at 4 hrs. 10 mins., which was 2 hrs. 50 mins. beyond the resistance period of the wall. (Temperature curves in fig. 106.)

After cooling.—The exposed shells of three top courses were off. All other shells were in place and contained no visible cracks; 70 per cent of the exposed shells were loose; the webs holding 19 per cent of the exposed shells were cracked; and 7 per cent of the units were in good condition. The units most damaged were near the edges of the wall. A masonry specimen could not be taken from this wall for compression, as so many of the exposed shells were loose. (Condition shown in fig. 37.)

TEST No. 82.—8 by 11 ft.; 8-in. wall plastered on both sides with gypsum plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*, laid on side. (Type 8–A–S.)—7 min.—plaster on lower middle of exposed side began to spall. About 2 sq. ft. of brown coat fell off at 16 min. 40 mins. to 2 hrs. 13 mins.—steam coming from wall condensing on unexposed surface. 1 hr. 15 mins.—botton joint near center of wall opened slightly, and center of wall slid about $\frac{1}{32}$ in. toward fire. 3 hrs. 50 mins.—smoke coming from cotton pad. Pad began to blaze and was removed at 4 hrs. 15 mins. 4 hrs. 10 mins.—fire shut off, as the resistance period of the wall was obtained at 3 hrs. 17 mins. (Temperature curves in fig. 107.)

After cooling.—Most of the exposed shells of the upper three courses fell off. All of the plaster on the remainder of the wall, except about 3 sq. ft. of brown coat, was in place. Plaster contained cracks outlining the individual tile units; 5 per cent of the exposed shells were loosened; the webs holding 30 per cent of the exposed shells were cracked; and 20 per cent of the units were in good condition. A masonry specimen taken from this wall failed under a load of 230 lbs./in.² (Condition shown in fig. 37.)

TEST No. 83.—4 by 4 ft.; 8-in. wall unplastered; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *m*. (Type 8–B–E, fig. 12a.)—[illegible] mins.—horizontal mortar joints on unexposed side beginning to open. 1 hr. [illegible] mins.—fire shut off. This test limit was chosen to obtain the effect of plaster in reducing the fire effect of short exposures. (Temperature curves in fig. 108.)

After cooling.—The exposed shell of one tile was loose, and the webs holding the shell of one tile were cracked. All others were in good condition or contained only minor cracks. (Condition shown in fig. 37.)

TEST No. 84.—4 by 4 ft.; 8-in. wall plastered on both sides with two coats of gypsum plaster and a white finish coat; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *m*. (Type 8–B–E, fig. 12a.)—5 to 16 mins.—bulging and spalling of several small patches of finish coat of plaster on exposed side. 20 to 28 mins.—all of finish coat of plaster covered with fine

cracks and spalling. 26 to 39 mins.—fine cracks in unexposed center horizontal mortar joints for length of 2 ft. 44 mins.—condensation of steam at 10 places opposite mortar joints on unexposed surface. 1 hr. 30 mins.—fire shut off. (Temperature curves in fig. 108.)

After cooling.—About 25 per cent of the finish coat of the plaster on exposed side was off. The remainder of the coat was checked. All of the plaster on the exposed side was calcined. All tile units were in good condition and free from cracks. Mortar in joints was hard. (Condition shown in fig. 37.)

TEST No. 85.—8 by 11 ft.; 8-in. wall plastered on the fire side with cement plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *m*. (Type 8–B–E, fig. 12a.)—11 to 15 mins.—some cracking and snapping sounds heard. 30 mins.—steam coming from imperfect mortar joints in upper part of wall and condensing in part on the unexposed surface. 1 hr. 45 mins.—bottom horizontal joint opened, and wall moved slightly toward the fire. 2 hrs. 48 mins.—smoke coming from the cotton pad. 2 hrs. 55 mins.—pad removed; the cotton in contact with the wall was smoldering, but did not blaze. Fire shut off at 6 hrs., which was 4 hrs. 16 mins. beyond the resistance period of the wall. (Temperature curves in fig. 109.)

After cooling.—No fire effects were noted, except shrinkage cracks in the cement plaster, these cracks generally outlining the tile units; 33 per cent of the exposed shells were loose. The webs holding exposed shells of 25 per cent of the units were cracked, but the shells were not loose; 38 per cent of the units were in good condition. Four units contained cracks beyond the longitudinal webs. A masonry specimen taken from this wall and tested in compression failed under a load of 265 lbs./in.^{2}. (Condition similar to wall 56, shown in fig. 30.)

TEST No. 86.—8 by 11 ft.; 8-in. wall plastered on both sides with gypsum plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *m*. (Type 8–B–E, fig. 12a.)—15 mins.—about 1 sq. ft. of the exposed plaster near center of the wall bulging. 25 mins.—exposed plaster bulging at three places in the lower south portion of the wall. 47 mins.—plaster bulging slightly at several places about 3 ft. from top of wall. 57 mins.—wet spots appeared over nearly all the mortar joints on the unexposed surface. 2 hrs. 6 mins.—nearly all of the wet spots had disappeared. 4 hrs. 2 mins.—smoke coming from cotton pad. When removed 4 mins. later, cotton blazed up. 6 hrs.—fire shut off. This was 2 hrs. 48 mins. beyond the resistance period of the wall. (Temperature curves in fig. 110.)

After cooling.—No fire effects were noted on the unexposed surface. About 10 per cent of the second coat of the exposed plaster was off, but all of the first coat remained in place; 16 per cent of the exposed shells were loose. The webs holding the exposed shells of 28 per cent of the units were cracked, but the shells were not loose; 56 per cent of the units were in good condition. No damage was found beyond the longitudinal webs. A masonry specimen taken from this wall and tested in compression failed under a load of 385 lbs./in.^{2}.

TEST No. 87.—8 by 11 ft.; 8-in. wall plastered on both sides with gypsum plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *m*. (Type 8–B–E, fig. 12a.)—15 mins.—snapping sounds coming from center of wall. 45 mins.—fine crack over lower horizontal unexposed side mortar joint extends halfway across wall. 1 hr. 20 mins.—about 4 sq. ft. of second coat of plaster in lower part of exposed side bulged. 40 mins. to 2 hrs. 10 mins.—steam from wall condensing on the unexposed surface. 3 hrs. 30 mins.—fire shut off to determine subsequent temperature rise on the unexposed surface. 4 hrs. 5 mins.—cotton pad removed; the cotton in contact with the wall was charred and the lower part glowing. (Temperature curves in fig. 111.)

After cooling.—No fire effects on unexposed side were noted. About 1 sq. ft. of second coat of plaster was off at bottom of exposed side. The cracks in the

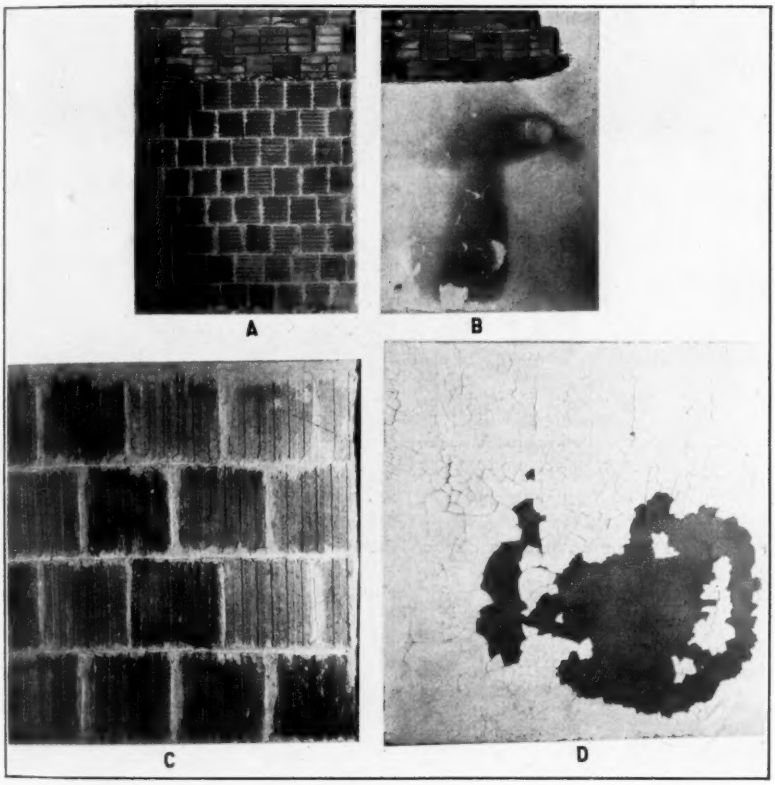


FIG. 37

A, exposed side of wall No. 81 after fire exposure of 4 hours 10 minutes
B, exposed side of wall No. 82 after fire exposure of 4 hours 10 minutes
C, exposed side of wall No. 83 after fire exposure of 1 hour 30 minutes
D, exposed side of wall No. 84 after fire exposure of 1 hour 30 minutes

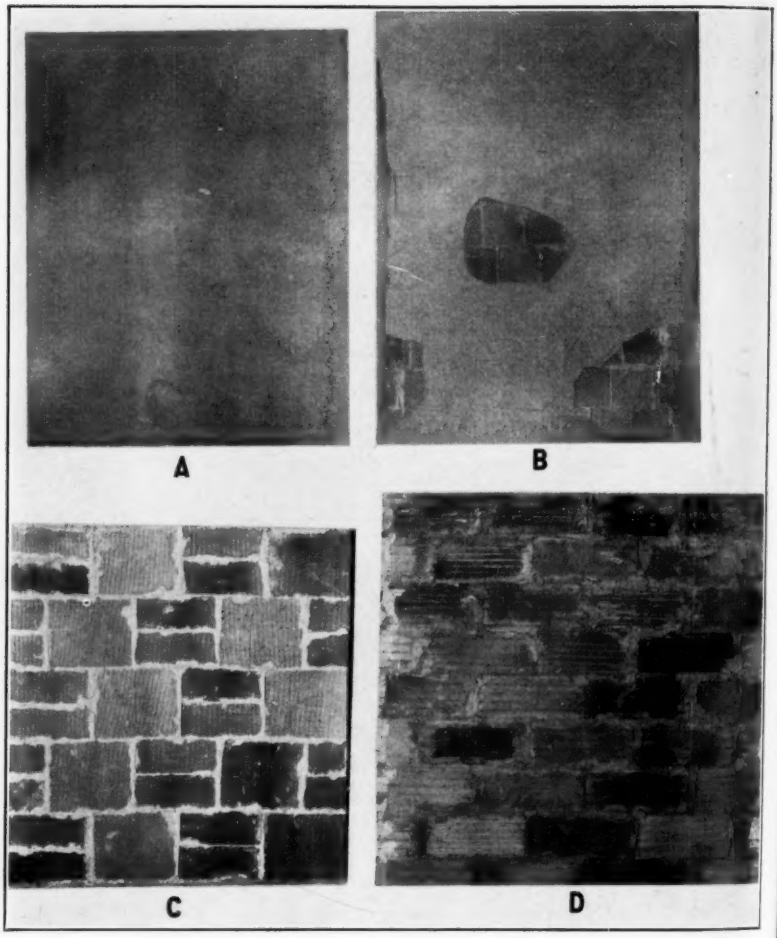


FIG. 38

A, exposed side of wall No. 87 after fire exposure of 3 hours 30 minutes
B, exposed side of wall No. 88 after fire exposure of 3 hours 30 minutes
C, exposed side of wall No. 92 after fire exposure of 1 hour 5 minutes
D, exposed side of wall No. 94 after fire exposure of 2 hours 42 minutes

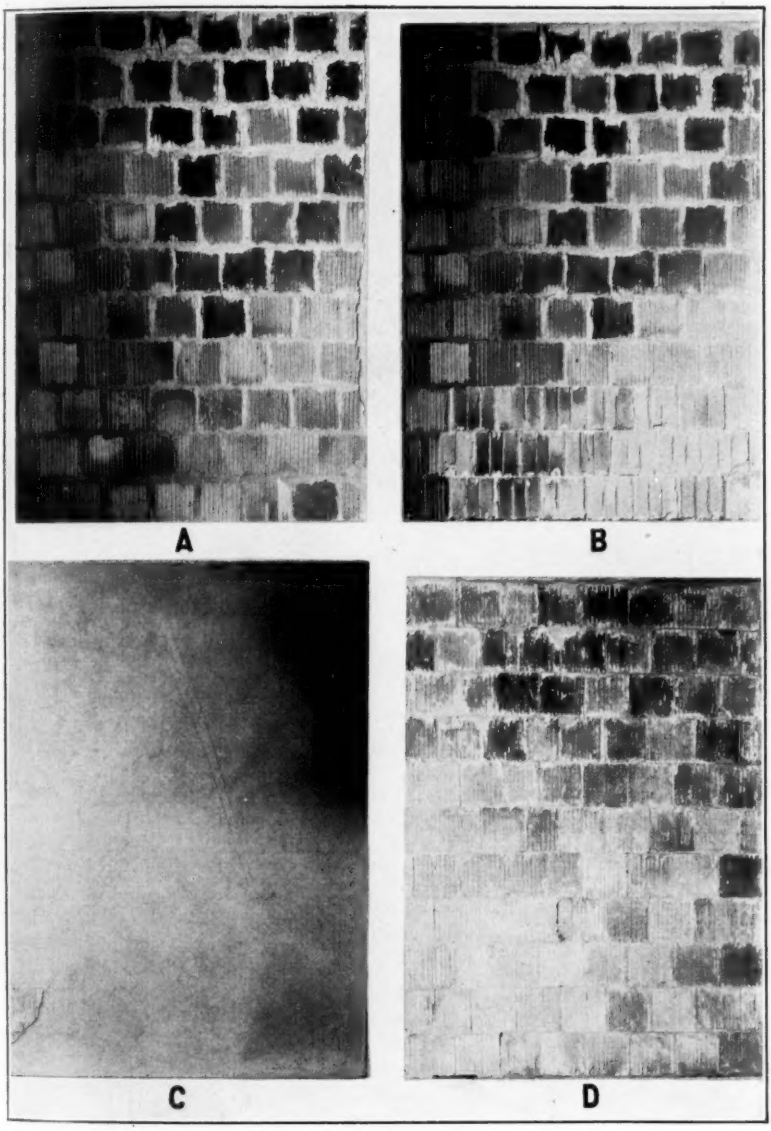


FIG. 39

A, exposed side of wall No. 89 after fire exposure of 6 hours
B, exposed side of wall No. 89 after removing some of loosened outer shells
C, exposed side of wall No. 90 after fire exposure of 6 hours
D, exposed side of wall No. 90 after removing plaster

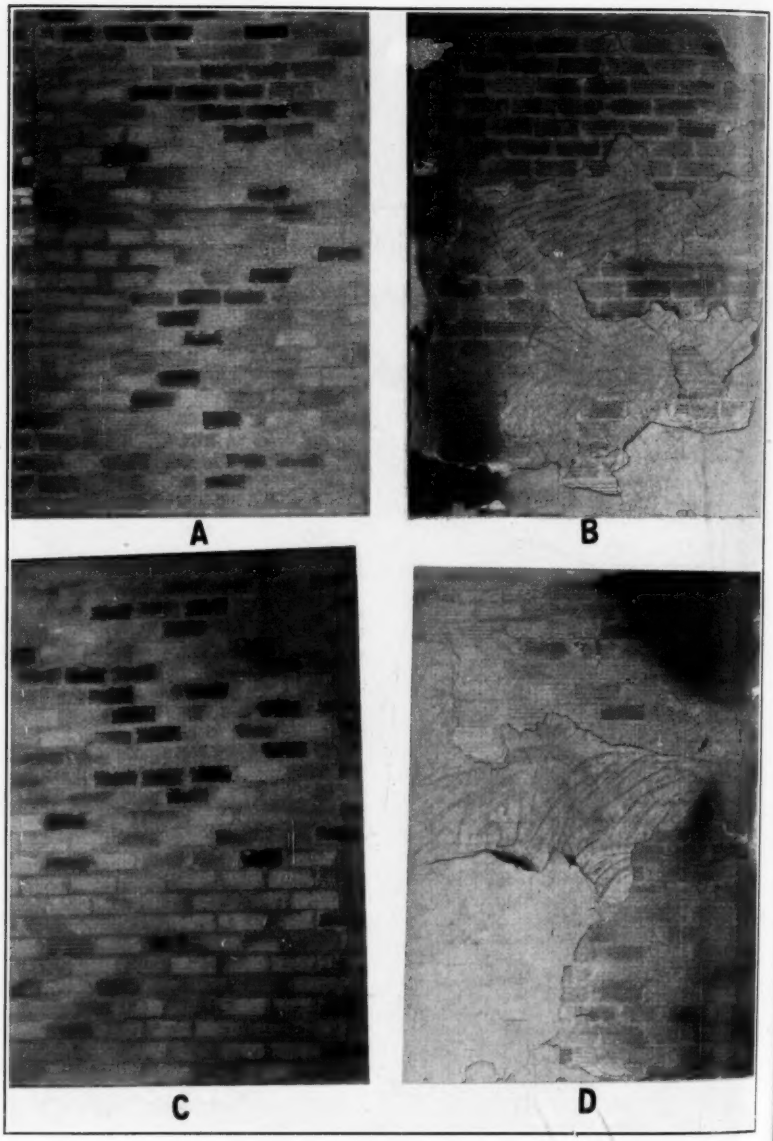


FIG. 40

A, exposed side of wall No. 95 after fire exposure of 4 hours 7 minutes
B, exposed side of wall No. 96 after fire exposure of 6 hours
C, exposed side of wall No. 97 after fire exposure of 4 hours 7 minutes
D, exposed side of wall No. 98 after fire exposure of 6 hours

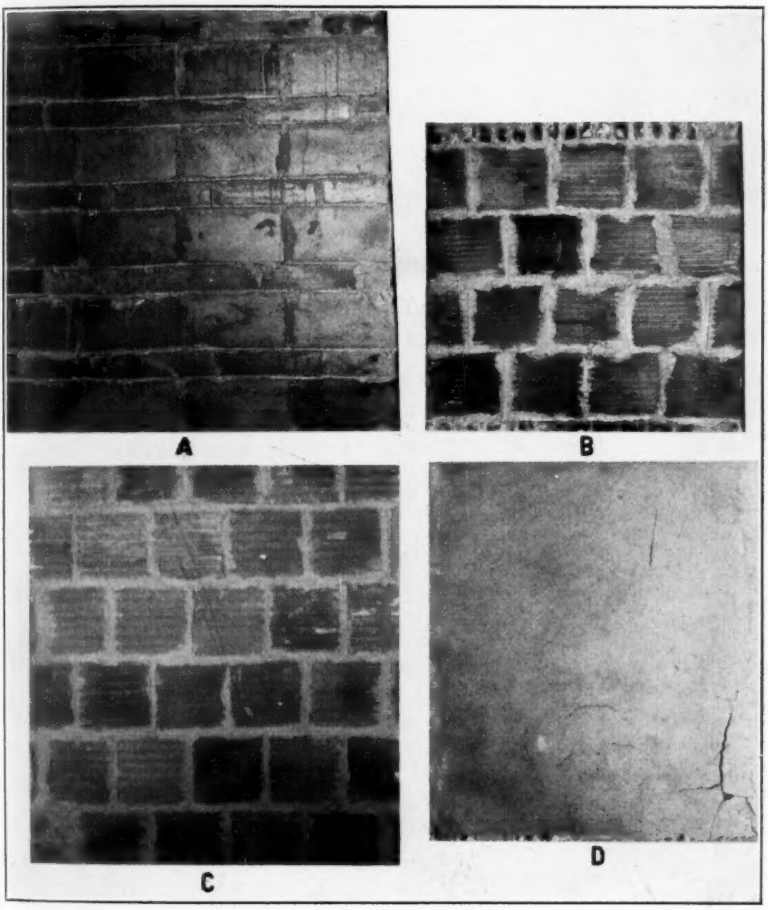


FIG. 41

A, exposed side of wall No. 101 after fire exposure of 6 hours
B, exposed side of wall No. 103 after fire exposure of 6 hours
C, exposed side of wall 107 after fire exposure of 3 hours 23 minutes
D, exposed side of wall No. 108 after fire exposure of 4 hours 53 minutes

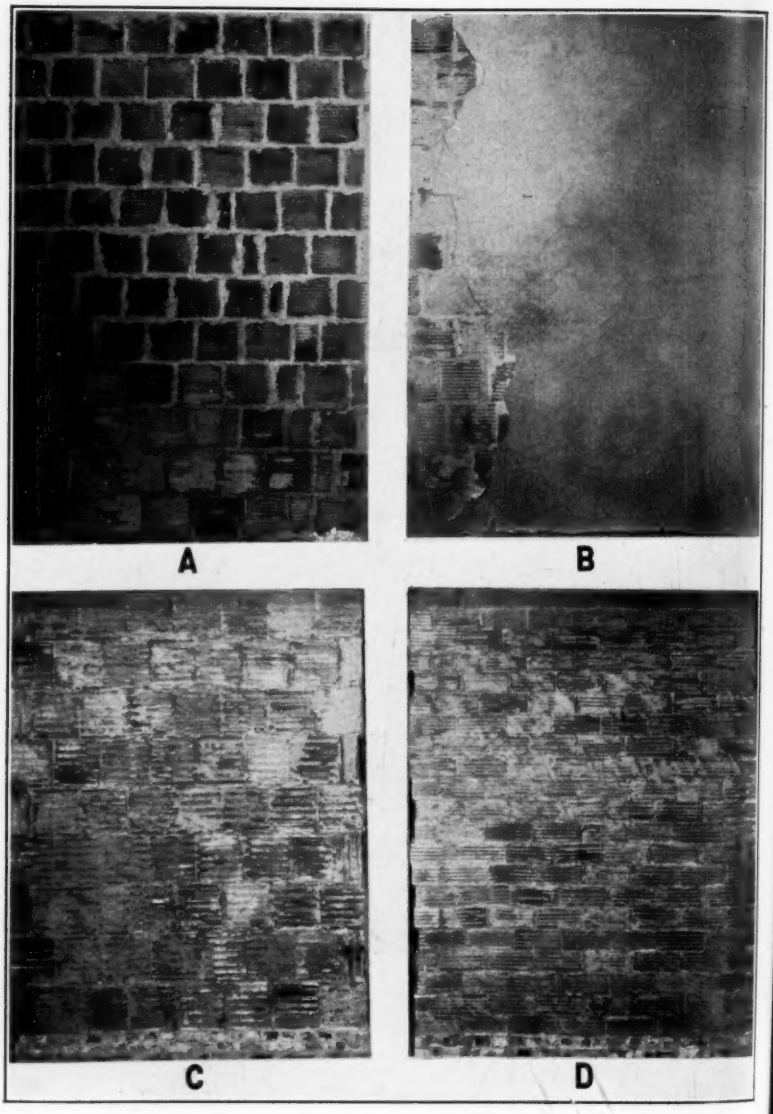


FIG. 42

A, exposed side of wall No. 105 after fire exposure of 6 hours
B, exposed side of wall No. 106 after fire exposure of 6 hours
C, exposed side of wall No. 110 after fire exposure and removal of plaster
D, exposed side of wall No. 111 after fire exposure and removal of plaster

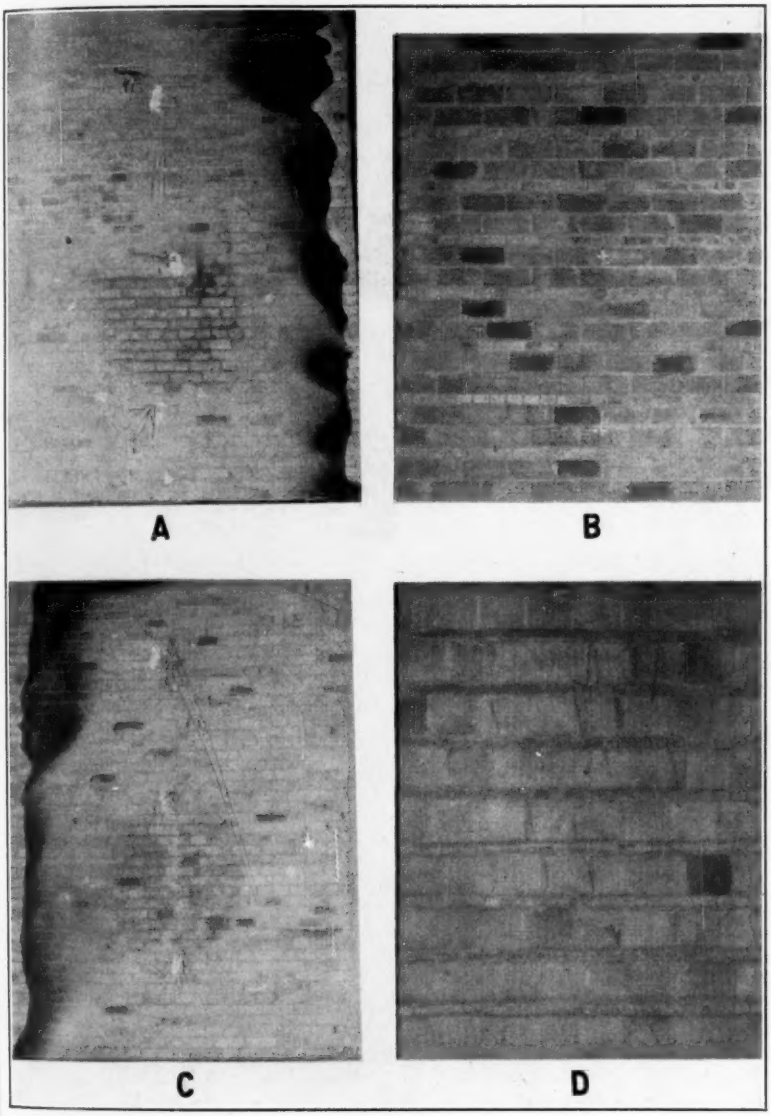


FIG. 43

A, unexposed side of wall No. 112 after fire exposure of 5 hours 31 minutes
B, exposed side of wall No. 112 after fire exposure and removal of plaster
C, unexposed side of wall No. 113 after fire exposure of 5 hours 31 minutes
D, exposed side of wall No. 113 after fire exposure and removal of plaster

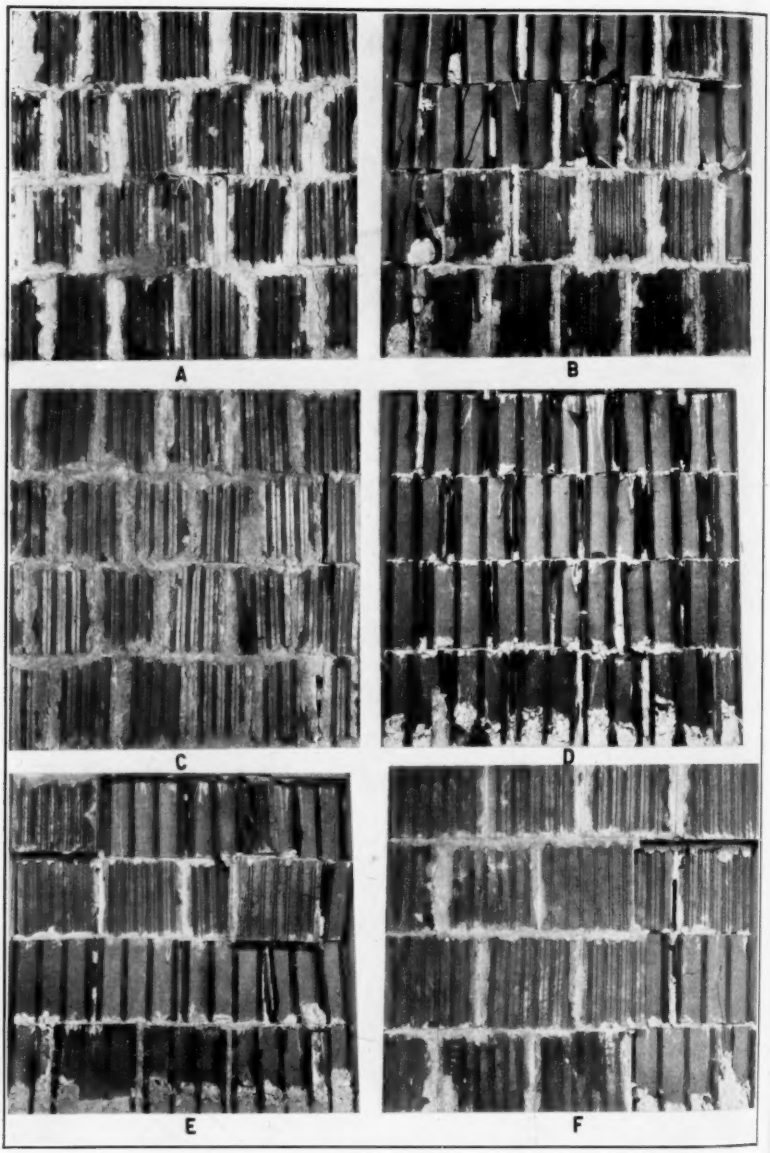


FIG. 44

A, unexposed side of wall No. 114 after fire exposure of 6 hours
B, exposed side of wall No. 114 after fire exposure of 6 hours
C, exposed side of wall No. 115 after fire exposure of 3 hours
D, exposed side of wall No. 115 after removing loosened shells
E, exposed side of wall No. 116 after fire exposure of 6 hours
F, exposed side of wall No. 117 after fire exposure of 3 hours

remainder of the plaster, in general, outlined the individual units. Nearly all of the tile were in good condition or contained only minor cracks. The wall could be reused by replastering. (Condition shown in fig. 38.)

TEST No. 88.—8 by 11 ft.; 8-in. wall furred and plastered on the fire side with gypsum plaster; restrained; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile and 2 by 12 by 12 in. split furring tile, both from source *m*. (Type 8–BI–E.)—20 mins.—about 2 sq. ft. of plaster near the center of exposed side bulged; this fell off at 56 mins. 1 hr. to 1 hr. 30 mins.—two additional patches of plaster bulged. 25 mins. to 2 hrs. 15 mins.—steam coming from and condensing in part on the mortar joints on unexposed side. 3 hrs. 30 mins.—fire shut off to determine subsequent temperature rise of wall. 4 hrs. 35 mins.—the cotton pad was removed; it was charred and smoking. (Temperature curves in fig. 112.)

After cooling.—About 10 sq. ft. of plaster on lower half of wall was off. The cracks in the remainder of the plaster, in general, outlined the tile units. Furring tiles were loose, due to dehydration of mortar, but they were broken only slightly. All tile in the structural part of the wall were in good condition. (Condition shown in fig. 38.)

TEST No. 89.—8 by 11 ft.; 8-in. wall unplastered; restrained; double-shell 8 by 12 by 12 in. end-construction fire-clay tile from source *m*. (Type 8–D–E, fig. 12c.)—12 mins.—some snapping sounds were heard. 36 mins.—bottom joint opened about $\frac{1}{16}$ in., and middle portion of wall slid slightly toward the fire. 25 mins. to 2 hrs.—steaming and condensation on unexposed side. 2 hrs. 25 mins.—smoke coming from excelsior-filled box; it was removed at 2 hrs. 47 mins., but did not blaze. Fire shut off at 6 hrs., which was 4 hrs. 1 min. beyond the resistance period of the wall. (Temperature curves in fig. 113.)

After cooling.—Seventy-five per cent of the outer exposed shells were loose and easily pulled off; 18 per cent had webs cracked, but the shells were not loose; 7 per cent were in good condition. Only 12 per cent of the units had cracks beyond the inner double shells. This wall could have been repaired by removing all of the outer exposed shells and plastering with a heavy coat of cement plaster. A masonry specimen taken from this wall and tested in compression failed under a load of 265 lbs./in.^{2}. (Condition shown in fig. 39.)

TEST No. 90.—8 by 11 ft.; 8-in. wall plastered on both sides with gypsum plaster; restrained; double-shell 8 by 12 by 12 in. end-construction fire-clay tile from source *m*. (Type 8–D–E, fig. 12c.)—36 mins.—bottom joint opened about $\frac{1}{16}$ in., and central portion of wall slid a small distance toward the fire. About 1 sq. ft. of the exposed plaster near the bottom of wall was loose. 50 mins.—wet spots appearing on the unexposed surface of the wall. 2 hrs. 50 mins.—all wet spots have disappeared. 5 hrs. 12 mins.—smoke coming from the excelsior-filled box. 5 hrs. 26 mins.—box removed, blazing. Fire shut off at 6 hrs., which was 1 hr. 46 mins. beyond the resistance period of the wall. (Temperature curves in fig. 114.)

After cooling.—No effects were noted on the unexposed surface. About 1 sq. ft. of the second coat of the exposed plaster was off; 8 per cent of the exposed shells were loose, the webs holding the outer exposed shells of 30 per cent of the units were cracked, but the shells were not loose; 14 per cent had cracks back of the inner double shell. All the other units were in good condition. This wall could have been repaired by removing loose shells and by replastering. A masonry specimen taken from this wall failed under a load of 385 lbs./in.^{2} (Condition shown in fig. 39.)

TEST No. 91.—4 by 4 ft.; 8-in. wall unplastered; 120 lbs./in.^{2} load; double-shell 8 by 12 by 10 in. and 8 by 12 by 5 in. end-construction fire-clay tile (without a center longitudinal web) from source *m*. (Type 8–E–E.)—(Two lengths of units were included in this wall to determine effect of size.) 7 mins.—some

cracking sounds were heard. 29 mins.—a loud cracking sound was heard. 1 hr. 6 mins. to 5 hrs.—vertical cracks appeared on the unexposed surface of about 25 per cent of the units, chiefly on those of 5-in. length. 1 hr. 5 mins.—steam coming from imperfect mortar joints. Fire shut off at 6 hrs., which was 4 hrs. 1 min. beyond the resistance period of the wall. (Temperature curves in fig. 115.)

After cooling.—Loads up to 160 lbs./in.^{2} (the capacity of the loading equipment) were applied, with only a few cracking sounds. Both sides of the wall appeared to be in perfect condition, except for the vertical cracks noted above. When the wall was dismantled, it was found that the long connecting webs of all of the units were broken (see A, fig. 11). No appreciable difference was noted in the damage to the short and the long units. (Condition similar to wall 92, shown in fig. 38.)

Test No. 92.—This wall was identical with No. 91, except that one-half of the short webs joining the two outer shells were omitted (see B, fig. 11). The test was continued for 1 hr. 5 mins. without causing noticeable fire effects. The test was stopped at this time because of shutdown of the compressor supplying the air for the burners. (Temperature curves in fig. 116.)

After cooling.—No fire effects were noted on the unexposed surface of the wall. Vertical cracks were noted on 75 per cent of the exposed shells. Some or all of the short connecting webs between the two double shells of all units were cracked, 20 per cent of the outer shells being loose. The long connecting webs of 15 per cent of the units were cracked, all these being units of short length. Generally, however, the failure was as is shown in B, Figure 11. (Condition shown in fig. 38.)

Test No. 93.—The same tile were used for this wall as for No. 92, except that the side of the units previously exposed was placed on the unexposed side for this wall. 50 mins.—some of the exposed side mortar joints spalled slightly. 1 hr. to 5 hrs. 40 mins.—fine vertical cracks formed on the unexposed surface of about 25 per cent of the units. Fire shut off at 6 hrs., which was 4 hrs. 8 mins. beyond the resistance period of the wall. (Temperature curves in fig. 116.)

After cooling.—All of the outer exposed shells were loose, due to the fracture of the short webs between the inner and outer double shells. In addition, many of the long transverse webs were also fractured, loosening the entire outer shell (see A, fig. 11). No difference was noted in fire damage to the long and the short units. (Condition similar to wall 92, shown in fig. 38.)

Test No. 94.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.^{2} load; 3-cell 8 by 5 by 12 in. side-construction fire-clay tile from source *h*. (Type 8–K–S, fig. 12b.)—5 mins.—small spall about 3 in. square from lower portion of exposed side of wall. 1 hr. 45 mins. to 2 hrs. 18 mins.—vertical cracks in mortar joints and across four tiles appeared on upper portion of unexposed side of wall. 2 hrs. 42 mins.—fire shut off. This was 30 mins. beyond the resistance period of the wall. Load increased to 120 lbs./in.^{2}. (Temperature curves in fig. 117.)

After cooling.—The wall carried 120 lbs./in.^{2} load. About 50 per cent of the units were split by vertical cracks; 63 per cent of the exposed shells were loose; the webs holding 25 per cent of the exposed shells were cracked, but the shells were not loose; and 12 per cent of the units had no cracks except the vertical cracks noted above. (Condition shown in fig. 38.)

Test No. 95.—8 by 11 ft.; 8-in. wall unplastered; unrestrained; 3-cell 8 by 5 by 12 in. side-construction fire-clay tile from source *m*. (Type 8–K–S, fig. 12b.)—9 mins.—a diagonal crack about 5 ft. long appeared across the lower south corner on the unexposed side. This crack opened to about $\frac{3}{16}$ in. at 24 mins. 32 mins.—steam coming from mortar joints and condensing in part on the unexposed surface. 1 hr. 20 mins.—the wet spots on the mortar joints have practically disappeared. 2 hrs. 15 mins.—smoke from cotton pad. 2 hrs. 17 mins.—pad removed; the cotton flamed in the lower corner, which had been over the crack

noted at 9 mins. 2 hrs. 55 mins.—a wide crack appeared on the unexposed surface where the wall joined the pilaster; a poor masonry bond obtained here. Fire shut off at 4 hrs. 7 mins., which was 2 hrs. 13 mins. beyond the resistance period of the wall. (Temperature curves in fig. 118.)

After cooling.—About 63 per cent of the exposed shells contained vertical cracks at the center opposite vertical mortar joints of courses above and below. Many of these cracks extended through the thickness of the unit, dividing it into two approximately equal lengths. Except for the above cracks, 41 per cent of the units were practically free from damage; 12 per cent of them had fractures in the webs holding the shell, but the shells were not loose; and the shells of 41 per cent of the units were loose. A masonry specimen taken from this wall and tested in compression failed under a load of 250 lbs./in.^{2}. (Condition shown in fig. 40.)

Test No. 96.—8 by 11 ft.; 8-in. wall plastered on both sides with gypsum plaster; restrained; 3-cell 8 by 5 by 12 in. side-construction fire-clay tile from source *m*. (Type 8–K–S, fig. 12b.)—(The plaster originally applied to this wall dried out before setting. That on the exposed side was removed and this side was replastered. A part of the second covering of plaster also dried out before setting.) 6 to 12 mins.—a considerable amount of the plaster on the fire side fell off. 43 mins.—nearly all of the plaster on fire side now off. 30 mins.—steam coming from wall and condensing at many places on the unexposed surface. 2 hrs. 10 mins.—practically all of the wet spots on the unexposed surface have disappeared. 4 hrs. 29 mins.—the excelsior-filled box removed, char and glow on one corner. Fire shut off at 6 hrs. This was 2 hrs. 40 mins. beyond the resistance period of the wall. (Temperature curves in fig. 119.)

After cooling.—No effects were noted on the unexposed surface, except minor cracks in plaster and stains from the steam which had condensed during the test. Nearly all of the second coat and 60 per cent of the first coat of the plaster on the exposed side was off. The shells of 20 per cent of the units were loose; the webs holding the exposed shells of about 15 per cent of the units were cracked, but the shells were not loose. About 65 per cent of the units were in good condition or contained only minor cracks in the exposed shell. No damage was found beyond the first longitudinal web. A masonry specimen taken from this wall and tested in compression failed under a load of 230 lbs./in.^{2}. (Condition shown in fig. 40.)

Test No. 97.—8 by 11 ft.; 8-in. wall unplastered; unrestrained; 2-cell 8 by 5 by 12 in. side-construction fire-clay tile from source *m*. (Type 8–L–S.)—12 mins.—a diagonal crack about 3 ft. long appeared on the unexposed surface in the mortar joints in lower north portion of wall. 25 mins.—three fine diagonal cracks following mortar joints have appeared near the center of the unexposed surface of the wall. 52 mins.—the bottom unexposed mortar joint opened about $\frac{1}{16}$ in. near center. 28 mins.—steam from mortar joints, with wet spots on unexposed surface. 1 hr. 20 mins.—practically all of the wet spots on the unexposed surface have disappeared. 2 hrs. 10 mins.—smoke coming from the cotton pad. 2 hrs. 18 mins.—cotton pad removed, blazing. Fire shut off at 4 hrs. 7 mins., which was 2 hrs. 36 mins. beyond the resistance period of the wall. (Temperature curves in fig. 120.)

After cooling.—About 69 per cent of the exposed shells contained vertical cracks at the center and over vertical mortar joints of adjoining tile. Many of these cracks extended through the thickness of the unit, dividing it into two lengths. Except for the vertical cracks, 61 per cent of the units were free from damage. The webs holding 8 per cent of the exposed shells were cracked, but the shells were not loose; 31 per cent of the exposed shells were loose. No damage was found beyond the first longitudinal web. A masonry specimen

taken from this wall and tested in compression failed under a load of 210 lbs./in.² (Condition shown in fig. 40.)

TEST No. 98.—8 by 11 ft.; 8-in. wall plastered on both sides with gypsum plaster; restrained; 2-cell 8 by 5 by 12 in. side-construction fire-clay tile from source *m*. (Type 8–L–S.)—(The plaster originally applied to this wall dried out before setting. That on the exposed side was removed and new plaster applied. A part of the second covering of plaster also dried out before setting.) 6 to 12 mins.—a considerable amount of the plaster on the fire side fell off. 43 mins.—about three-fourths of the plaster on the exposed side now off. 30 mins.—steam from wall condensing at many places on the unexposed surface. 2 hrs. 10 mins.—practically all of the wet spots on the unexposed surface have disappeared. 3 hrs. 21 mins.—excelsior-filled box blazed and was removed. Fire shut off at 6 hrs., which was 3 hrs. 37 mins. beyond the resistance period of the wall as determined by the temperature rise on the unexposed surface. (Temperature curves in fig. 121.)

After cooling.—No effects were noted on the unexposed surface, except stains from steam which had condensed during the test and minor cracks in the plaster. About 60 per cent of first coat and 80 per cent of second coat of plaster on the exposed side was off. The exposed shells of about 20 per cent of the units were loose and 20 per cent had cracks in the webs, but shells were not loose. About 60 per cent of the units were in good condition. Only one tile was damaged beyond center web. A masonry specimen taken from this wall and tested in compression failed under a load of 250 lbs./in.² (Condition shown in fig. 40.)

TEST No. 99.—4 by 4 ft.; 8-in. unplastered wall; 80 lbs./in.² load; 3-cell 8 by 5 by 12 in. side-construction fire-clay tile from source *l–2*. (Type 8–K–S, fig. 12b.)—50 mins.—steam coming from imperfect mortar joints on unexposed side. 1 hr. 30 mins. to 1 hr. 57 mins.—vertical cracks appeared on unexposed side of six units. 2 hrs. 11 mins.—fire shut off, as the resistance period of the wall was obtained at 2 hrs. 8 mins. 2 hrs. 15 mins.—load of 120 lbs/in.² was applied without cracking sounds. (Temperature curves in fig. 117.)

After cooling.—Load of 120 lbs./in.² was applied without cracking sounds from wall; 20 per cent of the units were broken by transverse cracks extending through the wall thickness. Although no exposed shells were off, 11 per cent of them were loose; the webs holding 28 per cent of them had decided cracks; and except for the vertical cracks previously noted, 61 per cent of the units were in good condition or contained only minor cracks. (Condition of tile similar to that of wall 95 shown in fig. 40.)

TEST No. 101.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction fire-clay tile from source *l–1*. (Type 8–O–S, fig. 12b.)—5 to 10 mins.—snapping sounds were heard. 12 mins.—small spall from exposed shell in lower right corner. 23 mins.—spalling of mortar on exposed side of lower part of wall indicates loosening of exposed shells. 45 mins.—steam coming from unexposed-side mortar joints. 1 hr. 30 mins. to 6 hrs.—fine vertical cracks usually opposite adjacent vertical joints appeared on some of the tile on the unexposed side of the wall. Fire shut off at 6 hrs., which was 3 hrs. 51 mins. beyond the resistance period of the wall. (Temperature curves in fig. 122.)

After cooling.—Load of 80 lbs./in.² was carried. The exposed shells were in place, but about 50 per cent of them were loose. In addition, about 40 per cent of the units were divided into two equal lengths by transverse vertical fractures. (Condition shown in fig. 41.)

TEST No. 102.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction fire-clay tile from source *l–1*. (Type 8–O–S, fig. 12b.)—12 mins.—cracking and snapping sounds were heard. 45 mins. to end of test—steam coming from unexposed side mortar joints. 1 hr. 30 mins.—

fire shut off. This test limit was chosen to determine the fire effects of short exposures. (Temperature curves in fig. 122.)

After cooling.—All of the exposed shells were in place, but the webs holding them were cracked so that the shells could be pulled off. No damage to the tile other than loosening of shells was noted. (Condition similar to that of wall 101, shown in fig. 41, except that the short test did not produce glazing on the exposed surface as for No. 101.)

TEST No. 103.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; H-shaped 8 by 10¼ by 12 in. side-construction fire-clay tile from source *l*. (Type 8–P–S, fig. 12c.)—55 mins.—a loud cracking sound was heard. 5 hrs. and 5 hrs. 30 mins.—a vertical crack appeared on unexposed side of two units. 45 mins.—steam coming from upper mortar joints. Fire shut off at 6 hrs., which was 4 hrs. 15 mins. beyond the resistance period. (Temperature curves in fig. 123.)

After cooling.—All of the exposed shells were in place, but nearly all of them were loose. About 50 per cent of the units also contained cracks back of the first longitudinal web. (Condition shown in fig. 41.)

TEST No. 104.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.² load; H-shaped 8 by 10¼ by 12 in. side-construction fire-clay tile from source *l*. (Type 8–P–S, fig. 12c.)—6 to 18 mins.—indistinct snapping sounds. 57 mins.—loud cracking sounds were heard. 1 hr. 20 mins.—a vertical crack formed, extending part way across the unexposed shell of one unit. 38 mins. to end of test—steam coming from the unexposed-side mortar joints. 1 hr. 30 mins.—fire shut off. This test limit was chosen to obtain the fire effects of short exposures. (Temperature curves in fig. 123.)

After cooling.—In cooling, fine vertical cracks appeared on nearly all of the exposed shells. Only minor cracks were found in or beyond the first longitudinal web. Although all of the exposed shells were in place, 22 per cent of them were loose; the webs holding 34 per cent of the shells were cracked, and 44 per cent of the units were in good condition or contained only minor cracks. (Condition similar to that of wall 103, shown in fig. 41.)

TEST No. 105.—8 by 11 ft.; 8-in. wall unplastered; restrained; H-shaped 8 by 10¼ by 12 in. side-construction fire-clay tile from source *l*. (Type 8–P–S, fig. 12c.)—30 mins.—some spalling from surface of lower part of exposed side of wall. 2 hrs. 10 mins. to 3 hrs. 52 mins.—cracks appearing in three lower horizontal mortar joints. 2 hrs. 45 mins.—smoke coming from cotton pad. 2 hrs. 59 mins.—cotton pad removed; cotton charred and part of wood of container glowing. Fire shut off at 6 hrs., which was 3 hrs. 34 mins. beyond the resistance period of the wall. (Temperature curves in fig. 124.)

After cooling.—No fire effects on unexposed side were noted. Surface of lower part of exposed side spalled. Although all exposed shells were in place, 25 per cent of them (mostly in lower portion) were loose, and the webs holding the remaining 75 per cent of the shells were cracked. In general, the units were not damaged beyond the first web parallel to the exposed surface. A masonry specimen cut from this wall failed under a load of 275 lbs./in.² (Condition shown in fig. 42.)

TEST No. 106.—8 by 11 ft.; 8-in. wall plastered both sides with gypsum plaster; restrained; H-shaped 8 by 10¼ by 12 in. side-construction fire-clay tile from source *l*. (Type 8–P–S, fig. 12c)—10 mins.—plaster bulging at edge next to unplastered complement wall. 40 mins. to 3 hrs. 45 mins.—steam coming from wall and condensing on unexposed-side plaster. 2 hrs. 10 mins.—fine crack appearing in lower horizontal mortar joint on unexposed side. 4 hrs. 38 mins.—smoke coming from cotton pad. 5 hrs. 3 mins.—cotton pad removed; part of cotton consumed and remainder charred. Fire shut off at 6 hrs., which was 1 hr. 8 min. beyond the fire resistance of the wall. (Temperature curves in fig. 125.)

After cooling.—The plaster was off from top to bottom and for about 2 ft. width next to complement wall. Remainder of plaster was covered with a network of fine cracks, with larger cracks generally outlining the tile units. None of the exposed shells were loose, but the webs holding about 50 per cent of them were cracked, the remaining units being in good condition or containing only minor cracks. A masonry specimen cut from this wall failed under a load of 340 lbs./in.^{2} (Condition shown in fig. 42.)

TEST No. 107.—4 by 4 ft.; 8-in. wall unplastered; 80 lbs./in.^{2} load; cube-shaped 8 by 8 by 8 in. side-construction fire-clay tile from source *f*. (Type 8–Q–S, fig. 12b.)—40 mins.—wet spots appeared on unexposed surface. 1 hr. 15 mins. to 2 hrs. 55 mins.—fine cracks appearing in vertical mortar joints on unexposed side; near the end of the test several of these cracks were opened $\frac{1}{32}$ to $\frac{1}{16}$ in., so that glow from the fire could be seen. Fire shut off at 3 hrs. 23 mins., which was 1 hr. 34 mins. beyond the resistance period of the wall. 3 hrs. 24 mins.—120 lbs./in.^{2} load carried without cracking sounds. (Temperature curves in fig. 126.)

After cooling.—A load of 80 lbs./in.^{2} was carried without cracking sounds from wall. Load increased to 120 lbs./in.^{2}, but some cracking sounds were heard; 70 per cent of the exposed shells were loose, and the webs holding the remainder were cracked; 10 per cent of the units were damaged beyond the first longitudinal web. (Condition shown in fig. 41.)

TEST No. 108.—4 by 4 ft.; 8-in. wall plastered both sides with gypsum plaster; 80 lbs./in.^{2} load; cube-shaped 8 by 8 by 8 in. side-construction fire-clay tile from source *f*. (Type 8–Q–S, fig. 12b.)—2 hrs. 3 mins.—wet spots begin to appear on unexposed surface. Fire shut off at 4 hrs. 53 mins., which was 1 hr. 20 mins. beyond the resistance period of the wall. No cracks or other effects visible on unexposed side. Load increased to 120 lbs./in.^{2} without cracking sounds. (Temperature curves in fig. 127.)

After cooling.—A load of 120 lbs./in^2 was carried without cracking sounds. About 1 sq. ft. of the exposed plaster was loose, but all of the plaster was in place; 29 per cent of the exposed shells were loose, the webs holding 17 per cent of the shells were cracked, and 54 per cent of the units were in good condition. (Condition shown in fig. 41.)

TEST No. 109.—4 by 4 ft.; 8-in. wall plastered on both sides with gypsum plaster; 120 lbs. per sq. in. load; cube-shaped 8 by 8 by 8 in. side-construction fire-clay tile from source *f*, laid on end. (Type 8–Q–E)—40 mins.—wet spots begin to appear on unexposed surface. 2 hrs. 30 mins.—fine diagonal crack appeared on unexposed surface and extended across one top corner. 4 hrs. 10 mins.—fine horizontal crack appeared on unexposed surface near top of wall. 4 hrs. 45 mins.—fire shut off, as the resistance period of the wall, as determined by the temperature rise on the unexposed surface, was obtained at 3 hrs. 35 mins. Load increased to 180 lbs./in.^{2} without cracking sounds. (Temperature curves in fig. 128.)

After cooling.—Load of 180 lbs./in.^{2} was carried without cracking sounds. The plaster was in place, but, in general, major cracks outlined the tile units. Five units at lower corner were cracked badly. All others were in good condition or contained only minor cracks. (Condition similar to that of wall 1 shown in fig. 41, except that no large cracks were present.)

TEST No. 110.—8 by 10⅓ ft.; 10-in. wall plastered on exposed side with gypsum and on unexposed side with cement; 110 lbs./in.^{2} computed stress produced in part by eccentricity of load of 2 in. toward exposed side; 3 cell 3¾ by 12 by 12 in. end-construction fire-clay tile from source *l*, laid on edge. (Type H–S, fig. 12a.)—The wall was built as two 3¾-in. walls spaced 2 in. apart and tied together with ¼ in. metal ties. 2 hrs. 7 mins.—steam coming from the wall and

densing on unexposed surface. 3 hrs. 45 mins.—fuel supply nearly exhausted; furnace temperatures dropped about 150° C. 4 hrs. 2 mins.—fire shut off, as the resistance period of the wall, as determined by the temperature rise on the unexposed surface, had been nearly obtained. 4 hrs. 5 mins.—load increased to give a fiber stress of 165 lbs./in.² (Temperature curves in fig. 129.)

After cooling.—165 lbs./in.² stress applied without cracking sounds. No visible effects on unexposed side. Cracks in plaster outline units of wall. All of the units in this wall were in good condition or contained only minor cracks. (Condition shown in fig. 42.)

TEST No. 111.—8 by 10⅓ ft.; 10-in. wall plastered on exposed side with gypsum plaster and on unexposed side with cement plaster; 110 lbs./in.² computed stress produced in part by eccentricity of load of 2 in. toward exposed side; 2-cell 3¾ by 5 by 12 in. side-construction fire-clay tile from source *l*. (Type 10-N-S.)—This wall was built as two 3¾-in. walls spaced 2 in. apart and tied together with ¼-in. metal ties. 2 hrs. 7 mins.—a small amount of condensation on the unexposed surface. 3 hrs. 45 mins.—fuel supply nearly exhausted; furnace temperatures dropped about 150° C. 3 hrs. 50 mins.—a fine horizontal crack formed in the plaster on the unexposed side over one mortar joint near mid height of wall. 4 hrs. 2 mins.—fire shut off, as the resistance period of the wall, as determined by the temperature rise on the unexposed surface, had been nearly obtained. Load increased to give computed stress of 165 lbs./in.². No cracking sounds were heard. (Temperature curves in fig. 130.)

After cooling.—A load giving a computed fiber stress of 165 lbs./in.² was applied. No effects on unexposed side. Plaster on exposed side covered with fine cracks, one prominent at the middle and extending from top to bottom of wall. Seven units were broken into two lengths by vertical fractures. All others were in good condition or contained only minor cracks. (Condition shown in fig. 42.)

TEST No. 112.—8 by 10⅓ ft.; 8-in. brick-faced wall plastered on tile side with gypsum plaster; 80 lbs./in.² load; 1-cell 3¾ by 5 by 12 in. side-construction fire-clay tile from source *m*. (Type 8–MZ–S, fig. 12c.)—(Masonry bond between the tile and brick was obtained by laying every fifth course of brick as headers.) 20 mins.—about 4 sq. ft. of plaster fell from exposed surface near one lower corner. 29 mins.—a small additional area of plaster fell off. 35 mins.—diagonal crack about 4 ft. long formed on the unexposed side across one lower corner. 45 mins. to 5 hrs.—steam coming from the wall and condensing on the unexposed mortar joints. 5 hrs. 31 mins.—fire shut off; this was 35 mins. beyond the resistance period of the wall. 5 hrs. 40 mins.—smoke coming from cotton pad; it was removed at 6 hrs. 5 mins.; a part of the cotton along one edge was consumed, the remainder being charred, but it did not blaze. 5 hrs. 55 mins.—load was increased to 120 lbs./in.² without cracking sounds. (Temperature curves in fig. 131.)

After cooling.—Load of 80 lbs./in.² was applied without noticeable effects. When increased to 120 lbs./in.², a few snapping sounds were heard. A small amount of the plaster on the exposed side was off, the remainder being covered with shrinkage cracks. The tiles were free from damage other than vertical cracks, which were found in 43 per cent of them. These cracks usually extended through the units, dividing them into two 6-in. lengths. Less than 1 per cent of the brick headers and about 8 per cent of the brick stretchers were broken. A masonry specimen taken from this wall and tested in compression failed under a load of 530 lbs./in.². (Condition shown in fig. 43.)

TEST No. 113.—8 by 10⅓ ft.; 8-in. brick-faced wall plastered with gypsum plaster on the fire side; 80 lbs./in.² load; 3-cell 3¾ by 12 by 10½ in. end-construction fire-clay tile from source *m*. (Type 8–JZ–E, fig. 12c.)—(Masonry bond

between the tile and brick was obtained by laying every fifth course of brick as headers.) 1 hr. 5 mins.—two short diagonal cracks following brick mortar joints appeared in the lower north corner of the unexposed side of the wall. 1 hr. 8 mins.—a fine vertical crack extending from top to bottom of the wall near the center of the unexposed side. 46 mins.—steam beginning to come from mortar joints on unexposed side of the wall; this continued until 5 hrs. 5 hrs. 31 mins.—fire shut off; this was 58 mins. beyond the resistance period of the wall. 5 hrs. 55 mins.—load was increased to 120 lbs./in.^{2}, with no sounds from wall. 6 hrs. 8 mins.—cotton pad removed; it did not blaze, but the cotton in contact with the wall was charred and smouldering. (Temperature curves in fig. 132.)

After cooling.—180 lbs./in.^{2} load applied without effect. No fire effects on the unexposed surface other than the fine cracks were noted. All of the plaster was in place but contained shrinkage cracks which generally outlined the tile units. All of the tiles were in good condition or contained only minor cracks. 2 per cent of the brick headers and 11 per cent of the stretchers were broken. A masonry specimen taken from this wall failed under a load of 575 lbs./in.^{2}. (Condition shown in fig. 43.)

TEST NO. 114.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.^{2} load; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *d*, set with the 8 by 12 in. face exposed. (Type 12–A–E, fig. 12a.)—2 to 15 mins.—cracking sounds heard. 1 hr. 30 mins.—exposed shells in the upper center of wall bulging, this increasing to 2 in. at 5 hrs. 2 hrs. 30 mins.—the bond of the end tile of second course was broken, and these units moved endwise, until at 5 hrs. 10 mins. they were in contact with the frame. 40 mins.—steam coming from the wall and condensing on the unexposed side mortar joints. 5 hrs. 58 mins.—wall failed under load by cracking and endwise movement of units of second and third courses. Fire shut off at 6 hrs., which was 3 hrs. 4 mins. beyond the resistance period of the wall, as determined by the temperature rise on the unexposed surface. (Temperature curves in fig. 133.)

After cooling.—Load not applied. Prominent cracks were noted, in the unexposed-side mortar joints and in the units near points where failure due to load occurred. All of the exposed shells were in place, but they were glazed and cracked so that many of them fell off when the wall was moved from the furnace. Cracks in the webs of the cells in the middle of the wall were formed so that, in addition to the exposed shells, the first longitudinal webs were generally loosened. (Condition shown in fig. 44.)

TEST NO. 115.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.^{2} load; 6-cell 8 by 12 by 12 in. end-construction shale tile from source *d*, set with 8 by 12 in. face exposed. (Type 12–A–E, fig. 12a.)—2 to 15 mins.—snapping and cracking sounds were heard. 10 mins.—minor flaking from exposed surface. 1 hr. 30 mins.—lower part of exposed shells of top course bulging. 25 mins.—steam coming from one mortar joint. 2 hrs. 30 mins.—no effect on unexposed side, except opening of some mortar joints. 3 hrs.—fire shut off so as to obtain the effects of this length fire exposure. This exposure was nearly equal to the resistance period of the wall, as determined by the temperature rise on the unexposed surface. Snapping and cracking sounds from wall for a few minutes after shutting off fire. (Temperature curves in fig. 134.)

After cooling.—A load of 120 lbs./in.^{2} was carried without any sign of failure. All of the exposed shells were in place. Two of the units had moved endwise and were in contact with the frame. The webs holding the remainder of the shells were cracked so that the exposed shells were easily loosened, but generally the cracks did not extend beyond the first longitudinal web. (Condition shown in fig. 44.)

TEST No. 116.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction shale tile from source *d*, bonded every course. (Type 12–AH–E, fig. 12a.)—15 mins.—not many cracking sounds. 1 hr.—steam coming from the wall at one mortar joint. 5 hrs. 45 mins.—vertical cracks were noted near middle of three unexposed shells. Fire shut off at 6 hrs., which was 2 hrs. 9 mins. beyond the fire-resistance period of the wall. Some of exposed shells softened and curled but remained in place. (Temperature curves in fig. 135.)

After cooling.—Load of 120 lbs./in.² was carried, but with some cracking sounds from wall. Fine vertical cracks in the middle of four unexposed shells. All of the exposed shells were loose. In dismantling the wall, it was found that all of the exposed tiles were decidedly cracked and that cracks were generally present also in the webs holding the shell nearest the fire side of the unexposed 8-in. units. Three of the unexposed 3¾-in. units were split by vertical cracks; the other five were in good condition. (Condition shown in fig. 44.)

TEST No. 117.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction shale tile from source *d*, bonded every course. (Type 12–AH–E, fig. 12a.)—2 mins.—cracking sounds were heard. 1 hr.—no fire effect on wall was noted. 1 hr. 30 mins.—steam coming from the wall and condensing on the unexposed-side mortar joints. 1 hr. 40 mins.—a diagonal crack appeared on the unexposed shell of the unit in one lower corner. 3 hrs.—fire shut off to determine fire effects from fires of shorter duration than the resistance period of the wall. (Temperature curves in fig. 136.)

After cooling.—A load of 120 lbs./in.² was easily carried. No fire effects were noted on the unexposed shells, except minor cracks in three units. All of the exposed shells were in place but were loosened so that about 30 per cent of them fell off in moving the wall from the furnace. Generally, no cracks were found in or beyond the first longitudinal web, so that all unexposed units were in good condition or contained only minor cracks. (Condition shown in fig. 44.)

TEST No. 118.—8 by 10⅓ ft.; 12-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction shale tile from source *d–1*. The supply of these tile was not enough for the full 10⅓ ft. height of this wall. The tile that were available were built in for 5 ft. of the middle portion of the wall, the courses above and below being of tile known to have better fire resistance. The report given here is confined to the behavior of the tile in the middle portion of the wall. (Type 12–O–S, fig. 12b.)—2 mins.—snapping sounds were heard. 22 mins.—occasional snapping sounds. 57 mins.—minor flaking from exposed surface. 5 hrs.—fire shut off to determine the effect of this test duration. Load was increased to 120 lbs./in.². Apparently this was near the load-carrying capacity of the wall. (Temperature curves in fig. 137.)

After cooling.—The exposed shells contained numerous cracks, most of which were horizontal. All but three of the exposed shells were in place, but the webs holding them were cracked so that 85 per cent of them were loose. These cracks extended back of the first but not beyond the second longitudinal web. The unexposed units were in good condition or contained only minor cracks. A masonry specimen cut from this wall failed under a load of 150 lbs./in.²

TEST No. 119.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.² load; 9-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *j*, set on end with the 8 by 12 in. faces exposed. (Type 12–C–E.)—Many snapping sounds were heard in applying load, and for this reason test was started with 80 lbs./in.² load. 1 min.—many snapping and cracking sounds were heard; these continued throughout test. 4 to 15 mins.—large spalls came from exposed shells; this continued throughout test. 19 mins.—loud cracking. 20 mins.—exposed shells bulge

slightly toward fire. 40 mins.—some exposed shells bulge about 2 in. toward fire. 5 mins. to 3 hrs. 35 mins.—many cracks appeared on unexposed side. 45 mins.—steam coming from wall and condensing on unexposed-side mortar joints. 2 hrs. 30 mins.—all of exposed shells in place, although apparently loose; load increased to 120 lbs./in.^{2} 3 hrs. 20 mins.—loud cracking sounds were heard, and two of the exposed shells near the middle of wall fell off. 3 hrs. 35 mins.—parts of several unexposed shells near middle of wall fell off. 4 hrs. 10 mins.—wall failed under load. Fire shut off. (Temperature curves in fig. 138.)

After cooling.—All exposed shells were off or loose. The remaining portions of the units were cracked, the cracks extending into the webs of the unexposed side cell and, for some units, to the unexposed shell. (Condition shown in fig. 45.)

TEST No. 120.—4 by 4 ft.; 12-in. wall unplastered; 80 lbs./in.^{2} load; 9-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction surface-clay tile from source *j*. (Type 12–CH–E.)—2 mins.—small spalls coming from surface of several exposed shells. 15 mins.—thin spalls have fallen from nearly all exposed shells of two lower courses. 4 hrs. 23 mins.—steam coming from wall and condensing on the unexposed mortar joints. 5 hrs. 23 mins.—fire shut off, as resistance period of the wall, as based on temperature, was reached at 5 hrs. 22 mins. Load was increased to 87 lbs./in.^{2} when the wall failed, buckling outward 5 in. at the joint between the top two courses. (Temperature curves in fig. 139.)

After cooling.—All of the unexposed shells were free from cracks, except one tile of the top course. All of the exposed shells were off and all exposed units shattered. The 3¾-in. units on the unexposed side were not damaged, except where caused by the failure under load. (Condition similar to that of wall 121, shown in fig. 45.)

TEST No. 121.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.^{2} load; 9-cell 8 by 12 by 12 in. end-construction surface-clay tile from source *j*. (Type 12–CH–E.)—1 min.—cracking sounds were heard. 3 to 10 mins.—spalling to depth of scoring on exposed shells. 15 mins.—exposed shells in two top courses bulging. 1 hr. 20 mins.—the exposed shell of one tile in the third course fell off. 2 hrs. 20 mins.—diagonal cracks on unexposed side through two units. 2 hrs. 50 mins.—loud cracking sounds were heard, and the upper portion of the wall buckled out slightly. 3 hrs. 30 mins.—several of the exposed shells fell off. 4 hrs. 20 mins.—additional exposed shells fell off. 5 hrs. 40 mins.—one of the cracks on the unexposed side noted at 2 hrs. 20 mins. now open 3/16 in. 5 hrs. 45 mins.—loud cracking sounds were heard. 5 hrs. 50 mins.—failure started under full working load; load was partially released. 6 hrs.—fire shut off. (Temperature curves in fig. 140.)

After cooling.—Nearly all of the exposed shells were off and projecting webs glazed from incipient fusion. One end of wall on the unexposed side was cracked due to the failure under the load. Only a few of the 3¾-in. units on the unexposed side were in good condition. (Condition shown in fig. 45.)

TEST No. 122.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.^{2} load; 9-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction surface-clay tile from source *j*, bonded every course. (Type 12–CH–E.)—2 to 5 mins.—cracking sounds were heard. 8 to 15 mins.—small spalls from exposed surface of wall. 17 mins.—the exposed shells of five units in lower part of wall loose and bulging about 2 in. toward fire; this bulging increased, but the shells did not fall off during the test. 1 hr.—some loud cracking sounds were heard. 12 mins.—a fine diagonal crack was noted on the unexposed shell of one tile in one top corner of wall. 40 mins.—steam coming from wall and condensing on mortar joints. 3 hrs.—no further change in the wall noted. Fire shut off to determine the fire effects of this duration of fire. (Temperature curves in fig. 141.)

After cooling.—Load was not applied. No fire effects other than a few fine cracks were noted on unexposed side. All of the exposed shells were off or loose.

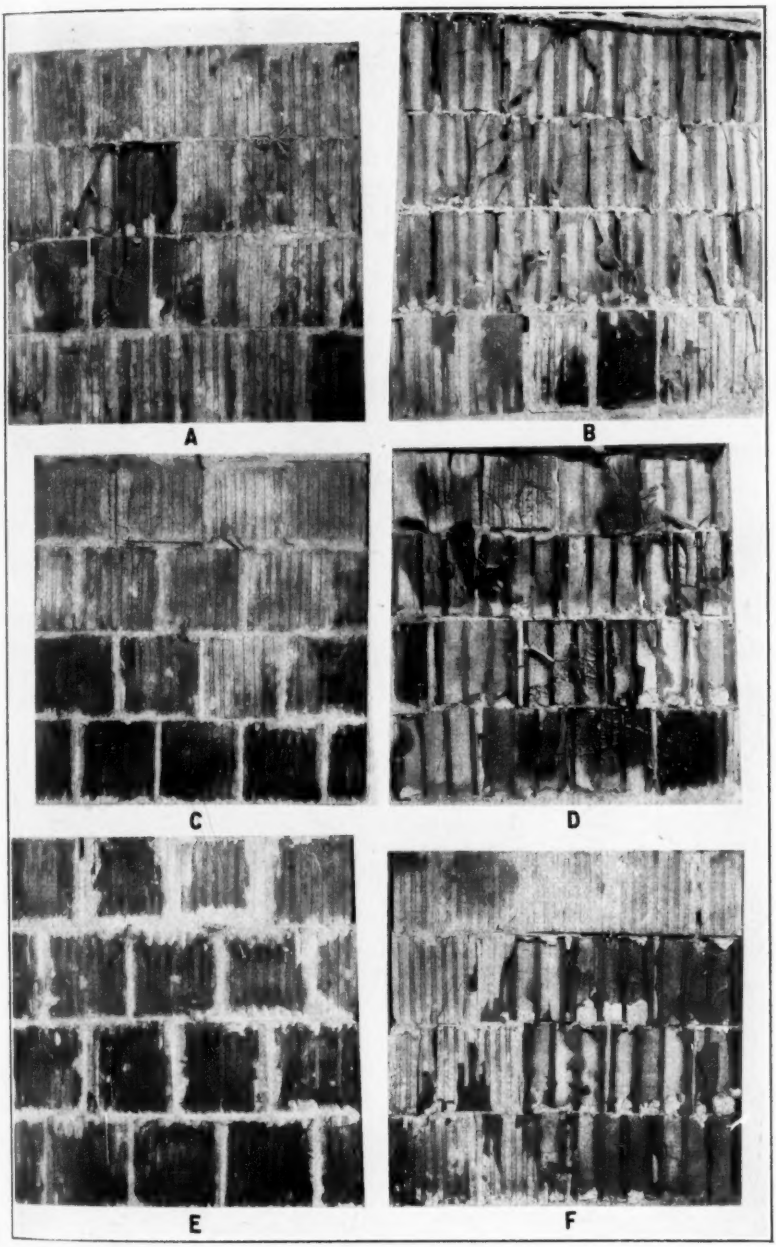


FIG. 45

A, unexposed side of wall No. 119 after fire exposure of 4 hours 10 minutes
B, exposed side of wall No. 119 after fire exposure of 4 hours 10 minutes
C, unexposed side of wall No. 121 after fire exposure of 6 hours
D, exposed side of wall No. 121 after fire exposure of 6 hours
E, unexposed side of wall No. 122 after fire exposure of 3 hours
F, exposed side of wall No. 122 after fire exposure of 3 hours

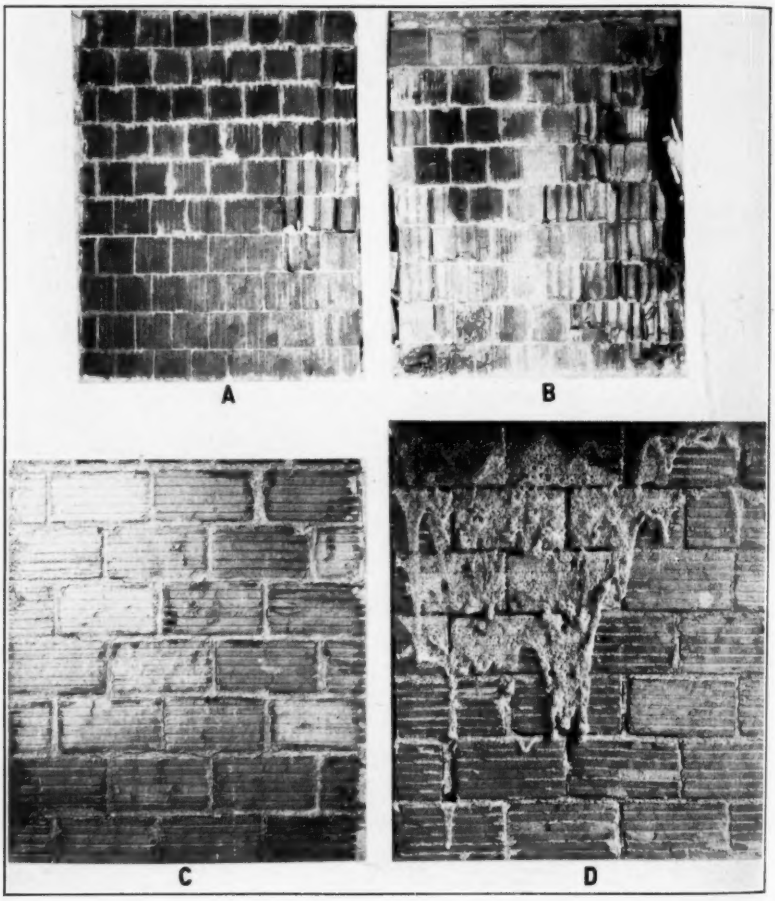


FIG. 46

A, exposed side of wall No. 124 after fire exposure of 5 hours
B, exposed side of wall No. 123 after fire exposure of 2 hours 22 minutes
C, exposed side of wall No. 125 after fire exposure of 8 hours 33 minutes
D, exposed side of wall No. 126 after fire exposure of 10 hours 42 minutes

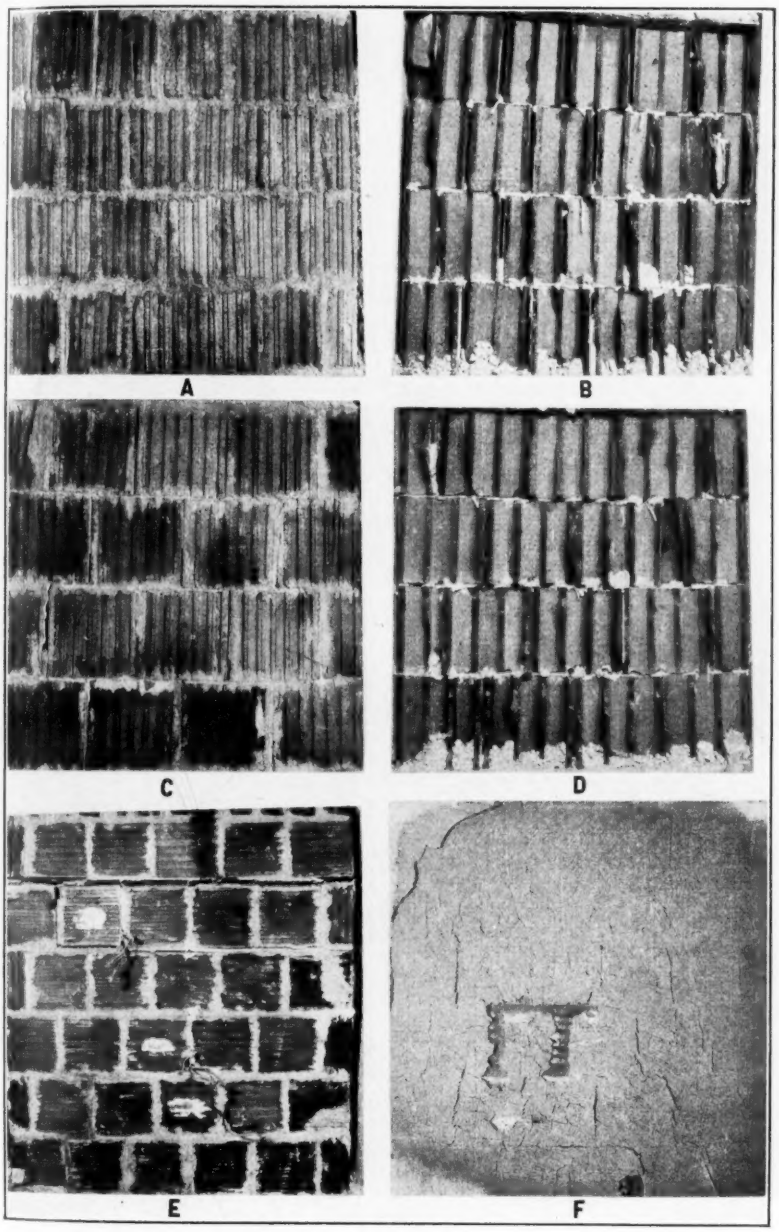


FIG. 47

A, exposed side of wall No. 130 after fire exposure of 6 hours
B, exposed side of wall No. 130 after removing loosened shells
C, exposed side of wall No. 134 after fire exposure of 3 hours
D, exposed side of wall No. 134 after removing loosened shells
E, unexposed side of wall No. 139 after fire exposure of 5 hours 32 minutes
F, exposed side of wall No. 140 after fire exposure of 8 hours 15 minutes

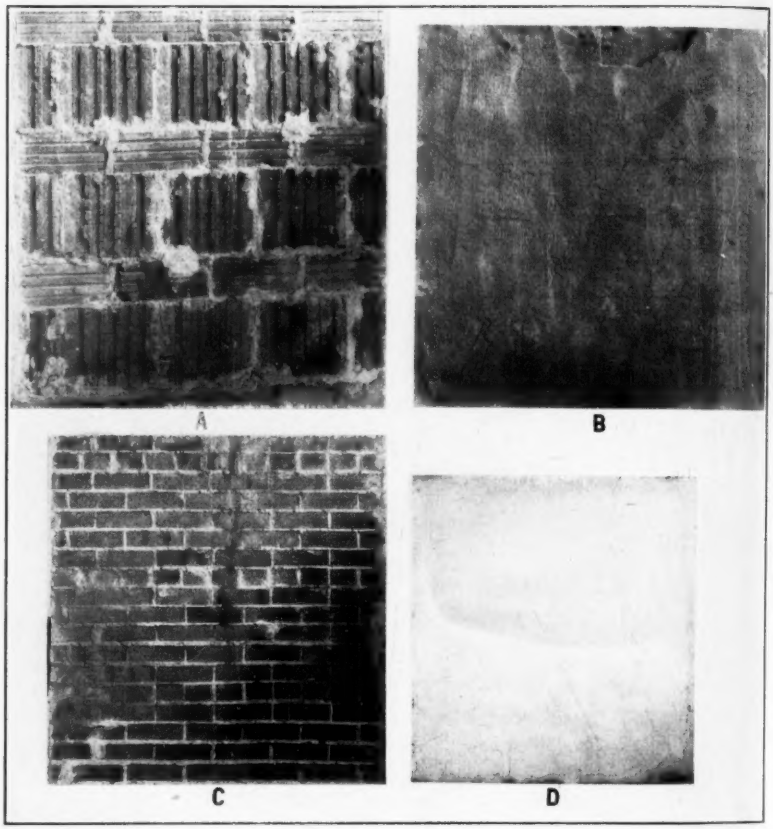


FIG. 48

A, exposed side of wall No. 141 after fire exposure of 4 hours
B, exposed side of wall No. 142 after fire exposure of 4 hours
C, exposed side of wall No. 143 after fire exposure of 4 hours
D, exposed side of wall No. 144 after fire exposure of 2 hours

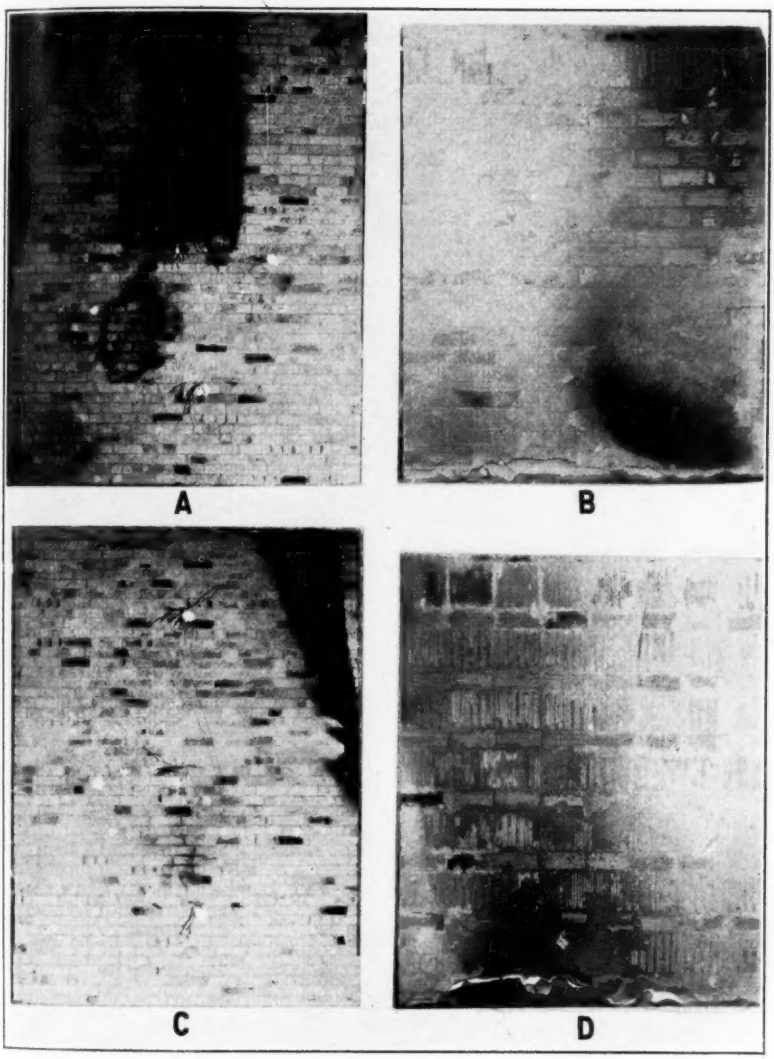


FIG. 49

A, unexposed side of wall No. 146 after fire exposure of 6 hours
B, exposed side of wall No. 146 after fire exposure of 6 hours
C, unexposed side of wall No. 147 after fire exposure of 6 hours
D, exposed side of wall No. 147 after fire exposure of 6 hours

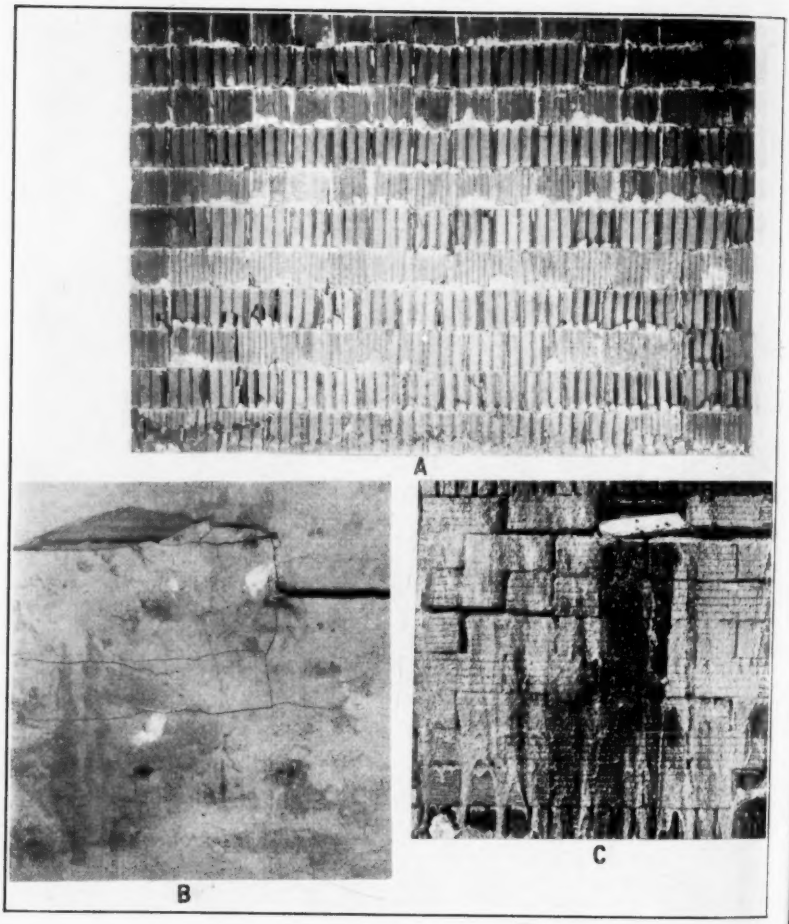


FIG. 50

A, exposed side of wall No. 148 after fire exposure of 5 hours 11 minutes
B, unexposed side of wall No. 158 after fire exposure of 12 hours 33 minutes
C, exposed side of wall No. 158 after fire exposure of 12 hours 33 minutes

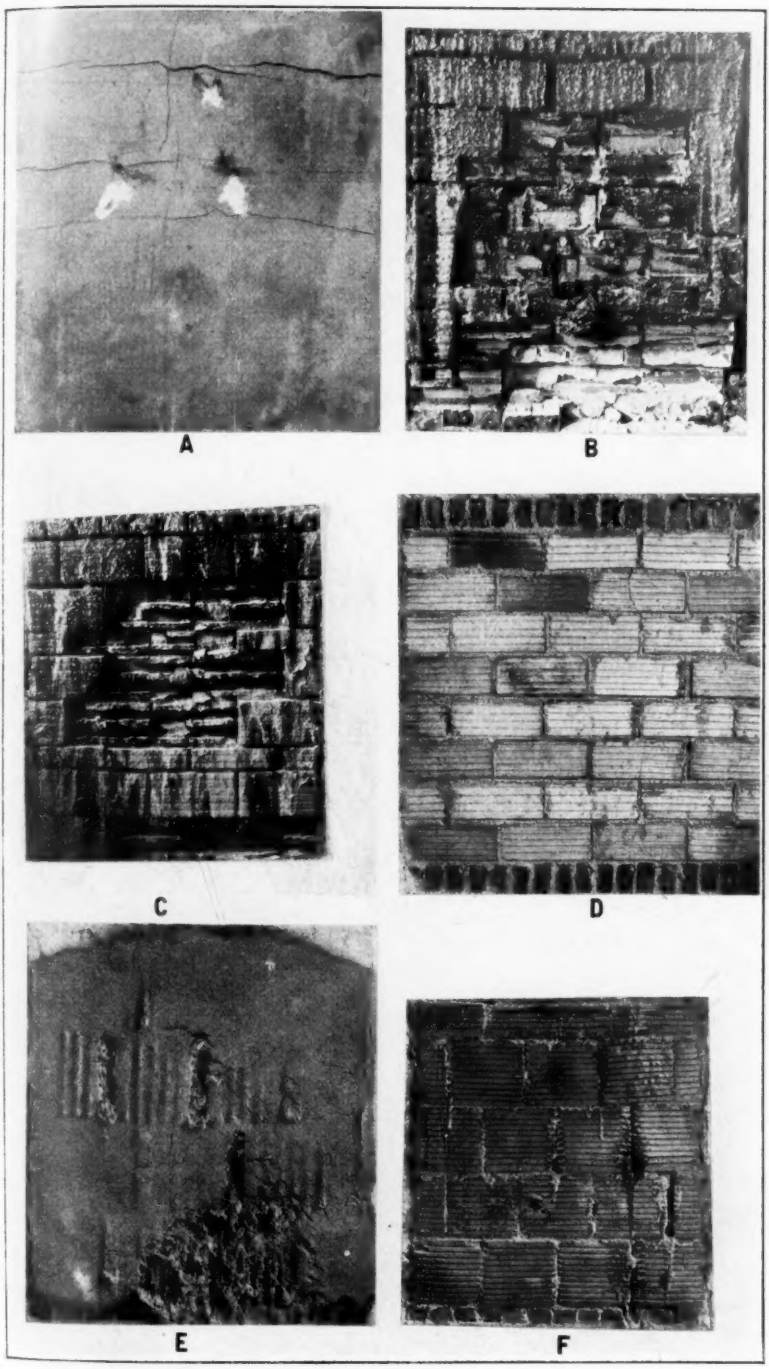


FIG. 51

A, unexposed side of wall No. 150 after fire exposure of 18 hours 10 minutes
B, exposed side of wall No. 150 after fire exposure of 18 hours 10 minutes
C, exposed side of wall No. 149 after fire exposure of 13 hours 48 minutes
D, exposed side of wall No. 157 after fire exposure of 8 hours 45 minutes
E, exposed side of wall No. 154 after fire exposure of 9 hours 24 minutes
F, exposed side of wall No. 160 after fire exposure of 10 hours 54 minutes

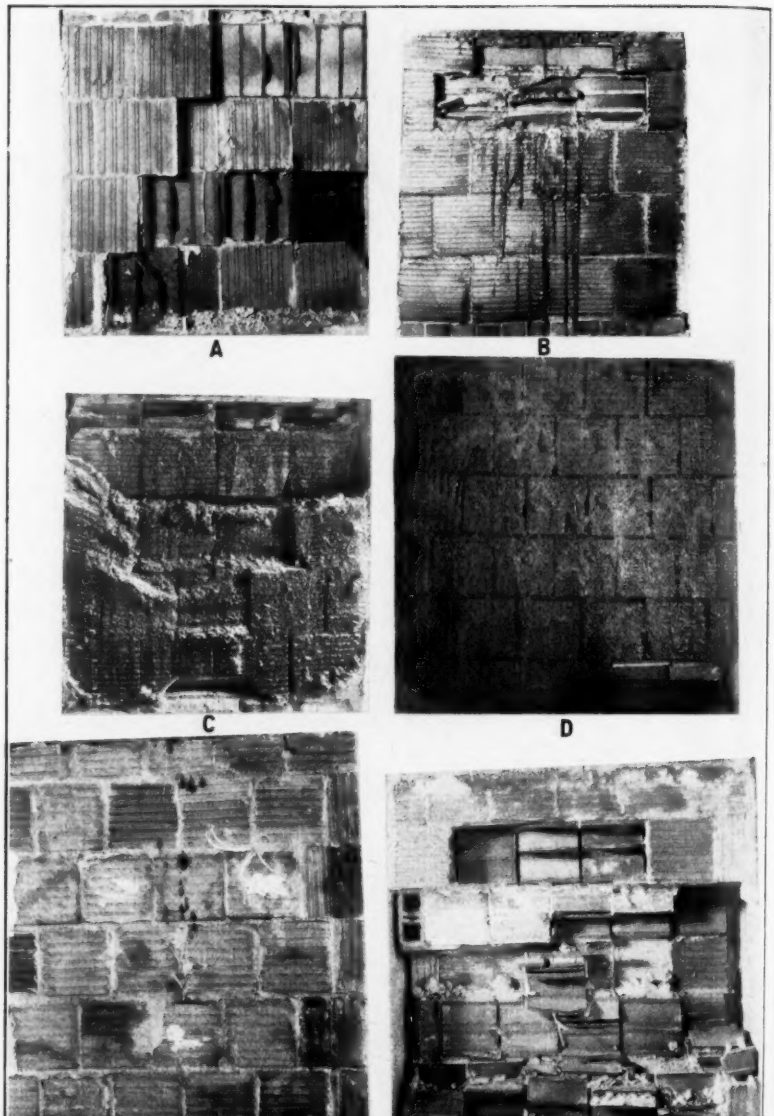


FIG. 52

A, exposed side of wall No. 133a after fire exposure of 3 hours 38 minutes
B, exposed side of wall No. 160a after fire exposure of 9 hours 3 minutes
C, exposed side of wall No. 161 after fire exposure of 14 hours 16 minutes
D, exposed side of wall No. 163 after fire exposure of 12 hours 45 minutes
E, unexposed side of wall No. 162 after fire exposure of 7 hours 1 minute
F, exposed side of wall No. 162 after fire exposure of 7 hours 1 minute

with cracks damaging the entire unit for those exposed to the fire. Shell and webs of the unexposed 8-in. units that were nearest the fire side were also damaged. The unexposed 3¾-in. units were not damaged. (Condition shown in fig. 45.)

TEST No. 123.—8 by 10⅓ ft.; 12-in. wall unplastered; 80 lbs./in.² load; 9-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction surface-clay tile from source *j*, bonded every course. (Type 12–CH–E.)—5 mins.—a few snapping sounds. 15 mins.—occasional snapping sounds. 30 mins.—the exposed shells in the lower 4 ft. of wall spalled to depth of scoring; shell of one of the side-construction filler tile at top of wall bulging out. 38 mins.—four filler tiles at top of wall failed. As these tile were different from those being tested, their failure can not be taken as failure of the wall. Hence, the load was released and the fire in part shut off, but the test of the complement wall was continued.

The top of the wall was repaired after cooling and the wall subjected to a second test. 9 mins.—several exposed shells at the end of one of the top courses came off. 24 mins.—exposed shells at one end of fourth and fifth course bulging. 52 mins.—exposed shells of five tiles near top corner of wall fell off. 1 hr. 17 mins.—additional exposed shells near bottom of wall fell off. 1 hr. 27 mins.—unexposed 8-in. end tile bonding fourth and fifth courses splitting. 1 hr. 52 mins.—further splitting similar to that noted at 1 hr. 27 mins. This end of wall not carrying full load, although wall as a whole carries the full 80-lb. load. 2 hrs. 2 mins.—part of one transverse shell at end of wall fell off. 2 hrs. 22 mins.—additional parts of units at one end fell off. Wall near point of failure. Fire shut off. (Temperature curves in fig. 142.)

After cooling.—Wall was not loaded. Except where failure occurred at end, no fire effects on the unexposed side were noted. Tile in approx. 8-in. width of wall at one end fell out. About 50 per cent of the exposed shells were off, the remainder being loose. A detailed examination of the individual units could not be made, but a general examination showed that the units were cracked to within 4 in. of the unexposed surface. The unexposed 3¾-in. tile were in good condition, except near the top at one end. (Condition shown in fig. 46.)

TEST No. 124.—8 by 10⅓ ft.; 12-in. wall unplastered; 80 lbs./in.² load; 6-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction surface-clay tile from source *k*. (Type 12–BJ–E.)—15 mins.—occasional snapping sounds. 30 mins.—spalling to depth of scoring of exposed shells in lower 4 ft. of wall. 38 mins. to 1 hr.—furnace temperatures irregular, due to shutting fire off complement wall (No. 123). 1 hr. 10 mins.—some additional spalling; this was continuous to the end of the test, but it was confined to portion of shells near exposed surface. 1 hr. 15 mins.—steam from a few unexposed-side mortar joints near top. 5 hrs.—fire shut off, as resistance period, determined by temperature rise, obtained at 5 hrs. 1 min. A load of 120 lbs./in.² was applied. One loud cracking sound was heard soon after the full load was applied. (This wall remained in position during the second test of its complement wall, the temperature in the furnace opposite the present wall being kept as low as possible.) (Temperature curves in fig. 143.)

After cooling.—Part of one shell at top of wall spalled off on application of overload. About 10 per cent of the exposed shells were off. The remainder were loose. Units on the unexposed side were generally in good condition or contained only minor cracks. (Condition shown in fig. 46.)

TEST No. 125.—4 by 4 ft.; 12-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *p–1*. (Type 12–O–S, fig. 12b.)—The load was applied only for the first 2 hrs. 32 mins. of the test, due to trouble with the loading equipment. 8 hrs. 33 mins.—no effects were noted on either side of wall. Fire shut off, as the resistance period of the wall, as determined by the temperature rise on the unexposed surface, was ob-

tained at 8 hrs. 32 min. A load of 80 lbs./in.² was carried with no cracking sounds during the application of the load. The overload could not be applied because of the condition of the loading equipment. (Temperature curves in fig. 144.)

After cooling.—Load could not be applied, as loading equipment was not in operative condition. Vertical cracks through middle of three units on the exposed side and two on the unexposed side. All of the exposed shells were in place, but about 40 per cent of them were loose. The webs holding the remainder were cracked to some extent, but in no case did the web cracks extend beyond the first longitudinal web. All of the unexposed units were in good condition, except for two that were broken into two lengths by vertical fractures. (Condition shown in fig. 46.)

TEST No. 125A.—4 by 4 ft.; 12-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *p–1*. (Type 12–O–S, fig. 12b.)—(This wall was dried to near constant weight before being tested.) Steam in appreciable quantity or other surface effects were not noted during the test. 5 hrs. 43 mins.—fire shut off, as the resistance period of the wall, determined by the temperature rise on the unexposed surface, was obtained at 5 hrs. 40 min. The load was increased to 120 lbs./in.² without any cracking sounds from wall. (Temperature curves in fig. 145.)

After cooling.—A load of 120 lbs./in² was carried without noticeable effects. No fire effects were noted in the unexposed side. Nothing but spalling of a small amount of scoring was noted on the exposed side. Cracks in the webs holding the exposed shells were found in about 35 per cent of the exposed units, and the shells of three units were loose. All of the unexposed units were in good condition. (Condition similar to that of wall 125, shown in fig. 46, except that the exposed surface was not glazed from incipient fusion.)

TEST No. 126.—4 by 4 ft.; 12-in. wall plastered on both sides with two coats of gypsum plaster; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *p–1*. (Type 12–O–S, fig. 12b.)—21 mins.—the exposed plaster on lower 12 in. of wall fell off. 7 hrs. 45 mins. to 8 hrs.—all of the exposed plaster, except some on upper 12 in. of wall, fell off. 10 hrs. 42 mins.—fire shut off, as the resistance period of the wall was obtained at 10 hrs. 43 mins. (Temperature curves in fig. 146.)

After cooling.—Easily carried 120 lbs./in.² load. No fire effects were noted on the unexposed surface, except very fine cracks in plaster, mostly horizontal, over mortar joints. All of the exposed plaster was off, except a small amount near the top which had fused. Mortar in joints in upper half of wall fused and run out for ½-in. depth. All of the exposed shells were in place, but the webs holding them were cracked so that they were loose. These cracks did not extend beyond the first longitudinal web. All unexposed units were in good condition. (Condition shown in fig. 46.)

TEST No. 127.—8 by 10⅓ ft.; 12-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *p–1*. (Type 12–O–S, fig. 12b.)—5 to 20 mins.—cracking sounds were heard. 32 mins.—spalls to depth of scoring from exposed shells of eight tiles in lower part of wall. 49 mins.—additional spalling taking place. 1 hr.—several minor vertical cracks have appeared on the unexposed surface. 3 hrs. 40 mins. to 4 hrs.—two vertical cracks following vertical mortar joints and breaking across tile formed across the middle of the unexposed side of the wall. 2 hrs. 20 mins.—steaming and condensation at several mortar joints on unexposed side. 5 hrs.—fire shut off. Load increased to 120 lbs./in.² which was apparently near the load-carrying capacity of the wall. (Temperature curves in fig. 147.)

After cooling.—No fire effects were noted on the unexposed side, except the vertical cracks noted above. All of the exposed shells were in place, but the webs holding about 50 per cent of them were cracked and about 20 per cent of the shells were loose. The remaining 50 per cent of the exposed units and all of the unexposed units were in good condition or contained only minor cracks. A masonry specimen cut from this wall failed under a load of 85 lbs./in.^{2} (Condition of tile similar to that of wall 125, shown in fig. 46, except that the surface was not glazed from incipient fusion.)

TEST No. 128.—8 by 10⅓ ft.; 12-in. wall unplastered; 80 lbs./in.^{2} load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *p-1*. (Type 12–O–S, fig. 12b.)—No effects were noted during the test other than some very fine vertical cracks following unexposed vertical mortar joints and breaking across intervening tile. These cracks were noted at 3 hrs. to 5 hrs. 30 mins. and, generally, were located near the center of the wall. Fire shut off at 6 hrs. The load was increased to 120 lbs./in.^{2} Some snapping sounds during its application. 6 hrs. 30 mins.—cotton pad removed. The cotton in contact with the wall was browned but not charred. (Temperature curves in fig. 148.)

After cooling.—Wall loaded to 80 lbs./in.^{2} without apparent effects. Although the wall appeared to be in good condition, the webs holding the exposed shells of nearly all of the units were cracked and 40 per cent of the shells were loose. Except for two units, cracking of the webs did not extend beyond the first longitudinal web. In addition, about 20 per cent of the units on the exposed side and 10 per cent of those on the unexposed side were divided by vertical fractures into two approximately equal lengths.

TEST No. 129.—8 by 10⅓ ft.; 12-in. wall plastered on both sides with 2-coat gypsum plaster; 80 lbs./in.^{2} load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *p-1*. (Type 12–O–S, fig. 12b.)—1 hr. 20 mins.—a fine vertical crack about 2 ft. long appeared on the unexposed surface near the bottom of wall. 4 hrs. 10 mins.—another vertical crack 5 ft. long near center of wall. Fire shut off at 6 hrs. The load was increased to 120 lbs./in.^{2} without visible effect. (Temperature curves in fig. 149.)

After cooling.—Wall loaded to 80 lbs./in.^{2}, which was carried safely. No fire effects were evident on the unexposed side. The cotton pad was charred, and cotton near center was consumed. All but 1 sq. ft. of the exposed plaster was in place, but it contained cracks which generally outlined tile units. About 40 per cent of the tile on the exposed side of the wall were in good condition or contained only minor cracks. The webs holding 60 per cent of the exposed shells were cracked, and 30 per cent of the exposed shells were loose. About 10 per cent of the units on the unexposed side had vertical cracks. A masonry specimen taken from this wall and tested in compression failed under load of 120 lbs./in.^{2} (Condition similar to wall 87, shown in fig. 38.)

TEST No. 130.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.^{2} load; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*, set with the 8 by 12 in. faces exposed. (Type 12–A–E, fig. 12a.)—2 mins.—some snapping sounds were heard. 26 mins.—a dull cracking sound was heard; no cracks were visible. 50 mins.—steam coming from unexposed mortar joints. 6 hrs.—no fire effects observed other than cracks in the unexposed mortar joints. Fire shut off. The fire duration was 3 hours and 15 mins. beyond the resistance period of the wall. (Temperature curves in fig. 150.)

After cooling.—A load of 120 lbs./in.^{2} was easily carried. Glazing of the exposed surface of the units in the lower part of the wall had begun. All of the exposed shells were in place, but they were loosened so that they were readily pulled off. The cracking of the webs extended beyond the first longitudinal web only for one tile. (Condition shown in fig. 47.)

TEST No. 131.—4 by 4 ft.; 12-in. wall unplastered 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. end-construction fire-clay tile from source *l*, set with the 8 by 12 in. face exposed. (Type 12–A–E, fig. 12a.)—3 to 5 mins.—faint snapping sounds were heard. 25 mins.—a small spall formed from exposed shell of one tile near the bottom of the wall. 1 hr. 10 mins.—exposed shells of the two top courses loose and bulging slightly toward fire; load dropped 30 per cent but was reapplied to full amount. 1 hr. 50 mins.—steaming from exposed side. 3 hrs.—fire shut off so that the fire effects of this fire duration could be noted. (Temperature curves in fig. 151.)

After cooling.—Load of 120 lbs./in.² was carried. No fire effects on unexposed side were noted. All of the exposed shells were in place, but loose. Cracks were found in the transverse webs beyond the first longitudinal web in 12 per cent of the units. (Condition similar to that of wall 130, shown in fig. 47.)

TEST No. 132.—16 by 11 ft.; 12-in. wall unplastered; unrestrained; 6-cell 8 by 12 by 12 end-construction fire-clay tile from source *l*, set with the 8 by 12 in. faces exposed. (Type 12–A–E, fig. 12a.)—12 mins.—an irregular crack having a maximum width of ⅛ in., following the unexposed-side mortar joints 1 ft. south of center of wall, extends full height of wall. 23 mins.—the crack noted at 12 mins. was open to about $\frac{3}{16}$ in. at the top. 48 mins.—a small vertical crack about 3 ft. long extends from top of wall 1 ft. north of center; a small vertical crack also appeared in the center of wall. 1 hr. 17 mins.—two other similar cracks appeared, one in upper, one in lower part of wall; all cracks noted were in unexposed-side mortar joints; they were caused in part by the short (4 in.) horizontal bond between units. 1 hr. 30 mins.—the crack noted at 12 mins. opened $\frac{1}{32}$ in.; it was possible to see the glow from the fire through it. 1 hr. 30 mins.—steaming from cracks at about 10 open joints in upper part of panel. 4 hrs.—smoke coming from cotton pad; as it was removed, the smoldering cotton blazed up. 4 hrs. 45 mins.—smoke coming from excelsior-filled box. 5 hrs.—excelsior-filled box burst into flame. 6 hrs.—fire shut off. This was beyond the resistance period of the wall as determined by temperature rise. The thermocouple installation did not function properly until 5 hrs. 8 mins., at which time the resistance period had been passed. (Temperature curves in fig. 152.)

After cooling.—Although none of the exposed shells had fallen off, 47 per cent of them were loose, and the webs holding 41 per cent of them were badly cracked; 12 per cent of the units were in good condition or contained only minor cracks. A masonry specimen taken from this wall and tested in compression failed under a load of 190 lbs./in.².

TEST No. 133.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction fire-clay tile from source *l*. (Type 12–AH–E)—20 mins.—first cracking sounds were heard. 25 mins.—small spalls coming from exposed shell in bottom course of wall. 40 mins.—some exposed shells appear to be loose and bulging slightly. 6 hrs.—no further fire effects were noted. Fire shut off. This was 1 hr. 57. mins. beyond the resistance period of the wall. (Temperature curves in fig. 153.)

After cooling.—No fire effects on unexposed side were noted. All of the exposed shells were in place, but the webs holding them were cracked so that about 50 per cent were loose. The cracking of the transverse webs did not extend back of the first longitudinal web. All of the units on the unexposed side of the wall were in good condition. (Condition similar to that of wall 134, shown in fig. 47, except that only one-half of the units had loosened shells.)

TEST No. 133A.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction fire-clay tile from source *l*. (Type 12–AH–E, fig. 12a.)—(This wall was dried to near constant weight before being tested.) Steam in appreciable quantity or other fire effects were

not noted during the test. 3 hrs. 38 mins.—fire shut off, as the resistance period of the wall, as determined by the temperature rise on the unexposed surface, was obtained at 3 hrs. 36 mins. 180 lbs./in.² load was applied. (Temperature curves in fig. 154.)

After cooling.—No cracks or other fire effects were observed on either the exposed or unexposed side of the wall. A load of 120 lbs./in.² was applied without cracking sounds. When the load was increased to 160 lbs./in.² the wall failed, and many of the exposed shells and a part of the wall fell out. Due to the failure under load, it was impossible to make detailed observations. Indications were that the fire damage extended beyond the first longitudinal web, but not into the 3¾-in. tile on the unexposed side. (Condition shown in fig. 52.)

Test No. 134.—4 by 4 ft.; 12-in. wall unplastered; 120 lbs./in.² load; 6-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction fire-clay tile from source *l*, set with the 8-in. tile on the fire side. 1 hr.—a few faint cracking sounds. 3 hrs.—no cracks or other fire effects were observed. Fire shut off so that the effects of this fire duration could be noted. (Temperature curves in fig. 155.)

After cooling.—No fire effects on unexposed side were noted. A vertical crack extended from top to bottom of wall on unexposed side entirely in tile and about 5 in. from end of wall. All of the exposed shells were in place, but they were loose. No cracks were found in the transverse webs back of the first longitudinal web. All of the 3¾-in. unexposed units were in good ocndition. (Condition shown in fig. 47.)

Test. No. 135.—8 by 11 ft.; 12-in. wall unplastered; restrained; 9-cell 12 by 12 by 12 in. end-construction fire-clay tile from source *n*. (Type 12–G–E, fig. 12a.)—10 mins.—part of tile ridges in the lower part of the wall spalled. 35 mins.—steam coming from imperfect unexposed mortar joints near top of wall. 1 hr.—steam condensing at a few points on unexposed side. 5 hrs. 12 mins.—smoke coming from cotton pad. 5 hrs. 26 mins.—cotton pad removed; half of cotton was consumed, remainder was glowing. Fire shut off at 6 hrs., which was 2 hrs. 43 mins. beyond the resistance period of the wall. (Temperature curves in fig. 156.)

After cooling.—No fire effects on unexposed side were noted. All of the exposed shells were in place, but a large percentage of the ridges of those in the lower part of the wall had spalled. The webs holding all of the exposed shells, however, were cracked, and most of the shells were loose. The cracking of the webs did not extend beyond the first longitudinal web. A masonry specimen cut from this wall failed under a load of 195 lbs./in.². (Condition similar to wall 69, shown in fig. 35.)

Test No. 136.—8 by 11 ft.; 12-in. wall plastered on both sides with two coats of gypsum plaster; restrained; 9-cell 12 by 12 by 12 in. end-construction fire-clay tile from source *n*. (Type 12–G–E, 12a.)—5 mins.—snapping sounds were heard. 20 mins.—about 1 sq. ft. of plaster at one end of wall bulging. 1 hr. 25 mins.—one wet spot on plaster near middle of wall. 5 hrs. 40 mins.—fine horizontal crack in unexposed-side plaster over mortar joint 4 ft. from top of wall. 6 hrs.—fire shut off. 9 hrs. 45 mins.—smoke from cotton pad. Pad ignited during night, probably near 10½ hrs., as estimated from temperature curve for the wall. (Temperature curves in fig. 157.)

After cooling.—About 1 sq. ft. of plaster along one edge of exposed side was off. The plaster was from ¾ to 1 in. thick. The webs holding the exposed shells were cracked so that about 75 per cent of the shells were loose. These cracks did not extend beyond the first longitudinal web. A masonry specimen cut from this wall failed under a load of 235 lbs./in.². (Condition similar to that of wall 68, shown in fig. 34.)

TEST No. 137.—4 by 4 ft.; 12-in. wall unplastered; 80 lbs./in.² load; H-shaped 8 by 10¼ by 12 in. side-construction fire-clay tile from source *l*. (Type 12–P–S.)—No fire effects were noted during the test. 5 hrs. 5 mins.—fire shut off, as the resistance period of the wall, as determined by the temperature rise on the unexposed surface, was obtained. Load was increased to 120 lbs./in.² without cracking sounds from wall. (Temperature curves in fig. 158.)

After cooling.—A load of 80 lbs./in.² was applied without noticeable effects. A few snapping sounds were heard when the load was increased to 120 lbs./in.² All of the exposed shells were in place but loose. In cases where the 8-in. tiles were exposed, the short transverse webs back of the first longitudinal webs were also cracked. None of the unexposed-side units were damaged.

TEST No. 138.—4 by 4 ft.; 12-in. wall plastered on both sides with gypsum plaster; 80 lbs./in.² load; H-shaped 8 by 10¼ by 12 in. side-construction fire-clay tile from source *l*. (Type 12–P–S.)—No fire effects of importance were noted during the test. 8 hrs. 34 mins.—fire shut off, as the resistance period, as determined by the temperature rise on the unexposed surface, had been nearly obtained. A load of 120 lbs./in.² was applied at the end of the test. (Temperature curves in Fig. 159.)

After cooling.—A load of 120 lbs./in.² was carried without noticeable effects. No fire effects of importance on unexposed side. All of the exposed plaster was in place, but fusion on its surface had begun. The webs holding about 30 per cent of the exposed shells were cracked, and a few of the shells were loosened. The remainder of the exposed units and all of the unexposed units were in good condition.

TEST No. 139.—4 by 4 ft.; 12-in. wall unplastered; 80 lbs./in.² load; 9-cell cube-shaped 8 by 8 by 8 in. side-construction fire-clay tile from source *f*. (Type 12–Q–S, fig. 12b.)—No fire effects were noted on exposed side during the test. 2 hrs. 30 mins.—wet spots on some unexposed side mortar joints. 5 hrs. 32 mins.—fire shut off, which was 1 hr. beyond the resistance period of the wall. No overload was applied. (Temperature curves in fig. 160.)

After cooling.—A load of 80 lbs./in.² was carried, but when increased to 100 lbs./in.² the exposed shells of the upper three courses fell off, and the wall failed by buckling outward. All of the exposed shells were loose. The fire damage generally extended to within 4 in. of the unexposed surface. (Condition shown in fig. 47.)

TEST No. 140.—4 by 4 ft.; 12-in. wall plastered on both sides with 2-coat gypsum plaster; 80 lbs./in.² load; 9-cell cube-shaped 8 by 8 by 8 in. side-construction fire-clay tile from source *f*. (Type 12–Q–S, fig. 12b.)—4 to 15 mins.—all of second coat of the exposed-side plaster fell off. 2 hrs. 30 mins.—first wet spot from steam on unexposed surface. 8 hrs. 15 mins.—fire shut off. This was 1 hr. 36 mins. beyond the resistance period of the wall. (Temperature curves in fig. 161.)

After cooling.—A load of 120 lbs./in.² was carried. All of the second coat of exposed-side plaster was off. A few patches of the first coat were also off. The plaster of the first coat had begun to fuse and contained large shrinkage cracks. All of the exposed shells were loose. Except in the top course, the web cracks did not extend beyond the first longitudinal web. (Condition shown in fig. 47.)

TEST No. 141.—4 by 4 ft.; 12-in. wall faced with brick but not plastered; 100 lbs./in.² load; 6-cell 8 by 12 by 10½ in. end-construction and L-shaped 8 by 5 by 12 in. side-construction heavy fire-clay tile from source *p*. (Type 12–VXZ–E, fig. 12c.)—The test of this wall with the tile side exposed to the fire was continued for 4 hrs., at which time no fire effects had been noted. The load was increased to 175 lbs./in.² (the capacity of equipment) without noticeable effect. (Temperature curves in fig. 162.)

After cooling.—A load of 175 lbs./in.² was carried without any cracking. The appearance of the wall indicated no fire effects, except a slight amount of spalling on the exposed surface of the wall. In dismantling the wall, however, it was found that the exposed shells were loose. The facing brick were not damaged. (Condition shown in fig. 48.)

TEST No. 142.—4 by 4 ft.; 12-in. wall faced with brick and plastered on the tile side with gypsum plaster; 100 lbs./in.² load; 6-cell 8 by 12 by 10½ in. end-construction and L-shaped 8 by 5 by 12 in. side-construction heavy fire-clay tile from source *p*. (Type 12–VXZ–E, fig. 12c.)—The test of this wall with the tile side exposed to the fire was continued for 4 hrs., at which time no fire effects were apparent. The load was increased to 175 lbs./in.² (the capacity of the equipment for 12-in. walls) without noticeable effects. (Temperature curves in fig. 163.)

After cooling.—A load of 175 lbs./in.² was carried without noticeable effects. All of the plaster on the exposed side was in place, but contained cracks which, in general, outlined the units. The webs holding the exposed shells were cracked to such an extent that the shells were loose or could be easily pulled away. The damage did not extend beyond the first longitudinal web. The facing bricks were not damaged. (Condition shown in fig. 48.)

TEST No. 143.—4 by 4 ft.; 12-in. wall faced with brick but not plastered; 100 lbs./in.² load; 6-cell 8 by 12 by 10½ in. end-construction and L-shaped 8 by 5 by 12 in. side-construction heavy fire-clay tile from source *p*. (Type 12–VXZ–E, fig. 12c.)—The brick side of this wall was subjected to the fire. The test of this wall was continued for 4 hrs., at which time no fire effects had been noted. The load was increased to 175 lbs./in.² (the capacity of the equipment for 12-in. walls) without visible effects. (Temperature curves in fig. 164.)

After cooling.—A load of 175 lbs./in.² was carried without any cracking. The tile were not affected by the test. The mortar in the exposed joints was calcined, and several vertical cracks extended downward from the top middle of the wall along the vertical mortar joints and across units; 21 per cent of the brick headers and 15 per cent of the stretchers were broken. (Condition shown in fig. 48.)

TEST No. 144.—4 by 4 ft.; 12-in. wall faced with brick and plastered on tile side with gypsum plaster; 100 lbs./in.² load; 6-cell 8 by 12 by 10½ in. end-construction and L-shaped 8 by 5 by 12 in. side-construction heavy fire-clay tile from source *p*. (Type 12–VXZ–E, fig. 12c.)—The test of this wall with the tile exposed to the fire was continued for 2 hrs., at which time no fire effects were noticeable. The load was increased to 175 lbs./in.² (the capacity of the equipment for 12-in. walls) without any visible effects. (Temperature curves in fig. 165.)

After cooling.—A load of 175 lbs./in.² was carried without apparent effects. No fire effects were noted on the unexposed surface. The plaster (⅝ to ¾ in. thick) on the exposed surface was in place but contained many fine cracks. Although the exposed shells were all in place, the webs in all but two of the units contained some cracks. About 50 per cent of the exposed shells were either loose or could be pulled off with a force estimated not to exceed 25 lbs. (Condition shown in fig. 48.)

TEST No. 145.—4 by 4 ft.; 12-in. wall plastered on the exposed side with gypsum plaster; 100 lbs./in.² load; 9-cell 12 by 12 by 10½ in. end-construction and L-shaped 12 by 5 by 12 in. side-construction heavy fire-clay tile from source *p*. (Type 12–WY–E.)—The test of this wall was continued for 1 hr., at which time no fire effects had been noted. The load was increased to 175 lbs./in.² (the capacity of the equipment for 12-in. walls) without visible effects. (Temperature curves in fig. 165.)

After cooling.—A load of 175 lbs./in.² was carried without cracking sounds from wall. No fire effects were noted on the unexposed side of the wall. The

plaster on the exposed side was in place and contained only very fine cracks. Minor cracks were found in the webs holding the exposed shells, but the shells were loose. They could be pulled off from only 25 per cent of the units. When removed from the wall, however, it was possible to knock off most of the other exposed shells by hammering from the inside.

TEST No. 146.—8 by 10⅓ ft.; 12-in. wall faced with brick and plastered on tile side with gypsum plaster; 80 lbs./in.² load; 2-cell 8 by 5 by 12 in. and 1-cell 3¾ by 5 by 12 in. side-construction fire-clay tile from source *m*. (Type 12-LMZ–S, fig. 12c.)—In the test the tile side was exposed to the fire. 3 mins.—about one-third of the plaster from the top part of the wall fell off. 1 hr. 25 mins.—all of the plaster now off, except a few sq. ft. in one lower corner. 15 mins.—a fine vertical crack formed near the middle of the unexposed side; this crack extended along the vertical mortar joints and across the brick until at 2 hrs. 10 mins. it was about 4 ft. long. 1 hr. 30 mins.—first steam coming from wall. 5 hrs. 15 mins.—a diagonal crack about 2 ft. long appeared across the upper corner of wall. 6 hrs.—fire shut off; load increased to 120 lbs./in.² without apparent effects. 8 hrs. 10 mins.—cotton pad burning. (Temperature curves in fig. 166.)

After cooling.—A load of 160 lbs./in.² (capacity of equipment) was applied without any cracking. All plaster was off, except about 20 per cent of the scratch coat. Although the wall appeared to be in good condition, only 4 per cent of the 8 by 5 by 12 in. units were free from cracks, 21 per cent had cracks in the webs holding the exposed shells, the shells not being loose, and the exposed shells of 75 per cent of the units were loose. Of the 3¾ by 5 by 12 in. units, 58 per cent were free from cracks, 32 per cent had webs cracked, and 10 per cent of the exposed shells were loose. Twelve per cent of the brick stretchers and 7 per cent of the headers were broken. A masonry specimen cut from this wall failed under a load of 220 lbs./in.² (Condition shown in fig. 49.)

TEST No. 147.—8 by 10⅓ ft.; 12-in. wall faced with brick and plastered on tile side with gypsum plaster; 80 lbs./in.² load; 6-cell 8 by 12 by 10½ in. end-construction and L-shaped 8 by 5 by 12 in. side-construction fire-clay tile from source *m*. Type 12–VXZ–E, fig. 12c.)—3 mins.—about one-third of the plaster from top part of wall fell off. 9 and 40 mins.—additional plaster fell off. 1 hr. 25 mins.—nearly all of plaster now off. 1 hr. 15. mins.—vertical crack about $\frac{1}{16}$ in. wide extending from center to the top of wall on unexposed side. 3 hrs. 40 mins.—vertical crack about $\frac{1}{32}$ in. wide near one end at mid height of unexposed side. 5 hrs. 15 mins.—diagonal crack about 2 ft. long across south upper corner of unexposed side. 6 hrs.—fire shut off; load increased to 120 lbs./in.² without apparent effects. 7 hr. 12 mins.—much smoke coming from cotton pad; pad was removed. (Temperature curves in fig 167.)

After cooling.—A load of 160 lbs./in.² (capacity of equipment) was applied. All of the plaster was off, except about 5 per cent of first coat. Of the 8 by 12 by 10½ in. units, 93 per cent were free from cracks, 4 per cent had cracks in the webs holding the exposed shells, the shells not being loose, and the exposed shells of 3 per cent of the units were loose. Of the L-shaped 8 by 5 by 12 in. units, 85 per cent were free from cracks, 9 per cent had cracks in the webs holding the exposed shells, the shells not being loose, and the exposed shells of 75 per cent of the units were loose. Eight per cent of the brick stretchers and 4 per cent of the headers were broken. A masonry specimen cut from this wall failed under a load of 360 lbs./in.² (Condition shown in fig. 49.)

TEST No. 148.—16 by 11 ft.; 16-in. wall unplastered; restrained; 6-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction shale tile from source *d*. (Type 12–AH–E, fig. 12a.)—½ to 20 mins.—continuous snapping and cracking sounds were heard. 20 mins.—small spalls noted from several exposed shells

in one lower corner of the wall. 30 mins.—the exposed shells on one end of the two lower courses bulging. 25 to 35 mins.—steam beginning to come from imperfect mortar joints and condensing on mortar joints. 45 mins.—about 4 sq. ft. of the exposed shells in top north corner fell. 1 hr. 7 mins.—all of the exposed shells of the lower three courses, except for 2 feet at the south end, fell off. 1 hr. 10 mins.—the exposed shells at the north end of the fourth, fifth, sixth, and seventh courses fell off; the remainder of the exposed shells of the lower three courses also fell off. 1 hr. 12 mins. to 1 hr. 15 mins.—six of the exposed shells at the south end of the fourth, fifth, and sixth courses fell off. 1 hr. 37 mins.—15 of the exposed shells in the middle of the fourth and fifth courses fell off. 1 hr. 58 mins.—about 30 sq. ft. of the exposed shells in the upper north portion of the wall fell off. 2 to 3 hrs.—continuous snapping and cracking sounds were heard, although no shells fell off during this period. 3 hrs. 50 mins.—about 42 sq. ft. of the exposed shells at the south center of the wall fell off. 4 hrs. 30 mins.—a vertical crack appeared on the unexposed side of the wall near the north end. 5 hrs. 11 mins.—so much material had fallen from the wall that the oil burners were nearly covered, and it was necessary to shut the fire off. This was 1 hr. beyond the resistance period of the wall, as determined by temperature rise on the unexposed surface. (Temperature curves in fig. 168.)

After cooling.—The excelsior-filled box showed no charring. The cotton pad was charred but did not ignite. The exposed shells of all 8-in. tile and all exposed 3¾-in. units were off, except that for four units in the third course and all units in the bottom course, where only the exposed shells of 3¾-in. tiles were off. All of the tiles were damaged, except the 3¾-in. units on the unexposed side and a few of the 8-in. units on this side. No masonry specimens were taken from this wall for compression tests. (Condition shown in fig. 51.)

Test No. 149.—4 by 4 ft.; 16-in. wall unplastered; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *p–1*. (Type 16–O–S, fig. 12b.)—20 mins.—small spalls coming from exposed surface of one tile near the bottom of wall. 12 hrs. 30 mins.—horizontal crack appearing in unexposed mortar joint 14 in. from the top of the wall. 13 hrs. 48 mins.—fire shut off, as the resistance period, as determined by the temperature rise on the unexposed surface, had been nearly obtained. (Temperature curves in fig. 169.)

Next morning—wall still hot.—A load of 80 lbs./in.² was carried. Some cracking sounds were heard during application of the load. The load was increased to 120 lbs./in.² No additional cracking. The exposed shells were loose or had fused and sloughed off. The fire damage extended 8 in. into the exposed side of the wall. All of the unexposed side units were in good condition or contained only minor cracks. (Condition shown in fig. 50.)

Test No. 150.—4 by 4 ft.; 16-in. wall plastered on both sides with 2-coat gypsum plaster; 80 lbs./in.² load; T-shaped 8 by 6¼ by 12 in. side-construction surface-clay tile from source *p–1*. (Type 16–O–S, fig. 12b.)—No steam from wall or condensation on unexposed surface was noted during the test. 11 hrs. 30 mins.—a horizontal crack forming on unexposed surface over mortar joints. 14 hrs. 10 mins. to end of test—furnace-control thermocouples were broken; furnace not controlled definitely, but same rate of gas consumption was continued during remainder of test. 18 hrs. 10 mins.—fire shut off, as the resistance period of the wall, as determined by the temperature rise on the unexposed surface, was reached. Wall still able to carry 80 lbs./in.² load. (Temperature curves in fig. 170.)

Next morning—wall still hot.—A load of 80 lbs./in² was carried, but apparently with small margin. The plaster on the unexposed side contained three horizontal cracks up to ¼ in. wide over the mortar joints near the top of the wall, extending for the full length of the wall. In addition, a vertical crack across the middle

of wall extended from top to bottom. All of plaster on the exposed side and nearly all of the shells were fused and sloughed off. All of the tile on the unexposed side of the wall were in good condition or contained only minor cracks. (Condition shown in fig. 51.)

TEST No. 151.—16 by 11 ft.; 16-in. wall unplastered; restrained; 6-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction fire-clay tile from source *l*. (Type 16–AH–E, fig. 12a.)—No cracking or spalling was noted during the test. 55 mins. to 5 hrs.—steam from wall and condensation in spots on unexposed side. 6 hrs.—fire was shut off, which was 53 mins. beyond the resistance period of the wall. 7 hrs. 49 mins.—smoke coming from cotton pad. 9 hrs. 11 mins.—cotton pad removed. The cotton burst into flame when exposed to the air. The excelsior-filled box placed against the unexposed side of the wall did not ignite. (Temperature curves in fig. 171.)

After cooling.—No fire effects were noted other than fine, short cracks on a few of the shells on the exposed side and in the mortar joints. Of the 3¾-in. tile exposed to the fire, 4 per cent had loosened shells; 24 per cent had cracks in the webs holding the shells, but they were not loose; 72 per cent were in good condition or contained only minor cracks. Of the 8-in. tile exposed to the fire, 22 per cent had loosened shells; 28 per cent had the webs holding the exposed shells cracked, but the shells were not loose; 50 per cent were in good condition or contained only minor cracks. None of the units not exposed directly to the fire were damaged. A masonry specimen taken from the wall and tested in compression failed under a load of 180 lbs./in.² (Condition similar to wall 75, shown in fig. 35.)

TEST No. 152.—16 by 11 ft.; 16-in. wall unplastered; unrestrained; 6-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction fire-clay tile from source *l*. (Type 16–AH–E, fig. 12a.)—7 mins.—indistinct snapping sounds were heard. 54 mins.—no fire effects were observed on the exposed side. 1 hr. 35 mins.—a fine vertical crack appeared on unexposed side near middle of wall, mainly in mortar joints; this crack lengthened, until at 4 hrs. 25 mins. it was about 8 ft. long. 6 hrs.—fire shut off. (Temperature curves in fig. 172.)

After cooling.—In dismantling, it was found that the exposed shells of 27 per cent of the 8-in. units and 7 per cent of the 3¾-in. units were loose; that the webs holding the exposed shells of 5 per cent of the 8-in. and 13 per cent of the 3¾-in. units were cracked, but the shells were not loose; that 68 per cent of the larger units and 80 per cent of the other size were in good condition or contained only minor cracks. A masonry specimen taken from this wall and tested in compression failed under a load of 165 lbs./in.²

TEST No. 153.—4 by 4 ft.; 16-in. wall unplastered; 150 lbs./in.² load; 6-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in. end-construction fire-clay tile from source *l*. (Type 16–AH–E, fig. 12a.)—2 hrs.—condensation first appearing on mortar joints on unexposed side; no other fire effects noted during the test. 6 hrs. 50 mins.—fire shut off. The temperature on the exposed surface was near 100° C. The test was stopped to determine temperature rise after fire was shut off. (Temperature curves in fig. 173.)

After cooling.—A load of 150 lbs./in.² was carried, with some cracking sounds during the application of the load. When 157 lbs./in.² load was reached, the wall failed by buckling outward at middle horizontal mortar joint. All of the exposed shells, except those in top course, were off. The cracking extended into the wall to a depth of 8 in. at some points. All units on the unexposed surface in good condition or contained only minor cracks. (Condition similar to that of wall 133A, shown in fig. 52.)

TEST No. 154.—4 by 4 ft.; 16-in. wall plastered on both sides with gypsum plaster; 150 lbs./in.² load; 6-cell 8 by 12 by 12 in. and 3-cell 3¾ by 12 by 12 in.

end-construction fire-clay tile from source *l*. (Type 16–AH–E, fig. 12a.)—30 mins. to 1 hr. 10 mins.—small wet spots appeared on the unexposed surface. 5 hrs. 55 mins.—fine horizontal crack appeared in the unexposed-side plaster over top horizontal mortar joint. 8 hrs. 50 mins.—fine crack appeared in unexposed-side plaster over middle horizontal mortar joint. 9 hrs. 24 mins.—fire shut off to determine subsequent temperature rise on the unexposed side. (Temperature curves in fig. 174.)

After cooling.—A load of 180 lbs./in.^{2} was applied, with only a few cracking sounds from wall. Only the fine horizontal cracks previously noted were found on the unexposed surface. The plaster on the exposed side had begun to fuse at the bottom and in spots near the middle of the wall. All of the exposed shells were loose, the damage extending into the wall to a depth of from 4 to 8 in. The units in the unexposed side were in good condition. (Condition shown in fig. 51.)

Test No. 155.—8 by 11 ft.; 16-in. wall unplastered; restrained; 2-cell 8 by 5 by 12 in. and 1-cell 3¾ by 5 by 12 in. side-construction fire-clay tile from source *m*. (Type 16–LM–S, bonded every third course.)—1 hr.—no fire effects were noted. 1 hr. 20 mins.—steam coming from the wall and condensing on a few unexposed-side mortar joints. 5 hrs.—practically all unexposed-side mortar joints now wet. 5 hrs. 25 mins.—unexposed-side mortar joints beginning to dry. 6 hrs.—fire shut off. 9 hrs.—much smoke was coming from the cotton pad. On removal, about one-half of the cotton in the center of the pad was consumed or smoldering but did not blaze. (Temperature curves in fig. 175.)

After cooling.—No fire effects were noted on the unexposed side. The exposed side appeared to be free from damage, but, in dismantling, it was found that about 75 per cent of the 8 by 5 by 12 in. units had exposed shells loose or the webs holding them cracked. Only 25 per cent of the 3¾ by 5 by 12 in. units were thus damaged. All units not directly exposed to the fire were undamaged. A masonry specimen taken from this wall and tested in compression failed under a load of 130 lbs./in.^{2} (Condition similar to wall 95, shown in fig. 40.)

Test No. 156.—8 by 11 ft.; 16 in. wall unplastered; restrained; 3-cell 8 by 5 by 12 in. and 1-cell 3¾ by 5 by 12 in. side-construction fire-clay tile from source *m*. (Type 16–KM–S, bonded every third course.)—1 hr. 20 mins.—steam coming from wall and condensing on the unexposed mortar joints near the bottom. 5 hrs.—practically all of the unexposed-side mortar joints now wet. 5 hrs. 25 mins.—the unexposed mortar joints beginning to dry. 6 hrs.—fire shut off. The cotton pad on the unexposed side did not ignite. (Temperature curves in fig. 176.)

After cooling.—No fire effects were noted on the unexposed side. The cotton pad had not ignited, but cotton in contact with wall was browned. Although the exposed side appeared to be in good condition, it was found that 80 per cent of the 8 by 5 by 12 in. units either had exposed shells loose or the webs holding them cracked. Only 25 per cent of the 3¾ by 5 by 12 in. units were damaged. All units not exposed directly to the fire were undamaged. A masonry specimen taken from this wall and tested in compression failed under a load of 120 lbs./in.^{2} (Condition similar to wall, 95 shown in fig. 40.)

Test No. 157.—4 by 4 ft.; 16-in. wall unplastered; 80 lbs./in.^{2} load; 3-cell 8 by 5 by 12 in. and 1-cell 3¾ by 5 by 12 in. side-construction fire-clay tile from source *m*. (Type 16–KM–S, fig. 12b.)—No fire effects on either side were noted during test. 8 hrs. 45 mins.—fire shut off to determine subsequent temperature rise on the unexposed surface. The load was increased to 120 lbs./in.^{2} without cracking sounds. (Temperature curves in fig. 177.)

After cooling.—A load of 120 lbs./in.^{2} was easily carried. No visible fire effects were noted on unexposed side. The mortar in the joints on the exposed side had

begun to fuse, but none had run out. All of the shells were in place and showed cracks on only one unit. However, all of them were loose. The units on the unexposed side of the wall were not damaged. (Condition shown in fig. 51.)

TEST No. 158.—4 by 4 ft.; 16-in. wall plastered on both sides with gypsum plaster; 80 lbs./in.² load; 3-cell 8 by 5 by 12 in. and 1-cell 3¾ by 5 by 12 in. side-construction fire-clay tile from source *m*. (Type 16–KM–S, fig. 12b.)—No effects were noted during first 8 hrs. of the test. 8 hrs. to end of test—could not see exposed side of wall. 12 hrs. 33 mins.—wall failed under load, crack forming near top of unexposed side of wall over horizontal mortar joint. 12 hrs. 34 mins.—fire shut off. (Temperature curves in fig. 178.)

After cooling.—Load was not applied. All of the exposed plaster was fused and had run off. The mortar near the fire side was fused and had run out of some vertical joints. The exposed shells were loose, and some stood out separated from the wall. All of the tile, except the 3¾ by 5 by 12 in. units on the unexposed side, were damaged. (Condition shown in fig. 50.)

TEST No. 159.—16 by 11 ft.; 16-in. wall unplastered; restrained; H-shaped 8 by 10¼ by 12 in. side-construction fire-clay tile from source *l*. (Type 16–P–S.)—30 mins.—fine cracks developing in horizontal mortar joints in lower part of unexposed side. 1 hr.—first steam coming from imperfect mortar joint near top center of unexposed side of the wall. 1 hr. 40 mins.—several unexposed mortar joints wet from steam. 5 hrs. 55 mins.—a few exposed shells in lower north corner of wall bulged. 6 hrs.—fire shut off. (Temperature curves in fig. 179.)

After cooling.—No fire effects were noted on the unexposed side. All of the exposed shells were in place, but a few of them were jarred off in moving the wall from the furnace. Forty-five per cent of the exposed shells for the 8-in. tile and 46 per cent for the 3¾-in. tile were loose. Thirty-seven per cent of the 8-in. tile and 44 per cent of the 3¾-in. tile were in good condition or contained only minor cracks. Eighteen per cent of the whole units, in addition to having their exposed shells loose, also had the webs connecting the two halves of the tile broken. No cracks were found beyond the 3¾-in. tile on the fire side of the wall. A masonry specimen for compression tests was not taken from this wall. (Condition similar to wall 103 shown in fig. 41.)

TEST No. 160.—4 by 4 ft.; 16-in. wall unplastered; 80 lbs./in.² load; H-shaped 8 by 10¼ by 12 in. side-construction fire-clay tile from source *l*. (Type 16-P–S.)—3 hrs. 15 mins.—condensation on one mortar joint on the unexposed side of the wall. No further effects were noted. 10 hrs. 45 mins.—fire shut off, as the resistance period of the wall, as determined by the temperature rise on the unexposed surface, was obtained at 10 hrs. 52 mins. The load was increased to 120 lbs./in.² without cracking sound being heard. (Temperature curves in fig. 180.)

After cooling.—A load of 120 lbs./in.² was carried. Many cracking sounds from wall during its application. No fire effects on unexposed side were noted. The mortar in joints on the exposed side was fused and had partly run out of some vertical joints. All of shells were in place but were loose. Cracks were also found in nearly all center horizontal webs of the exposed 8-in. units. All tile units not directly exposed to the fire were in good condition. (Condition shown in fig. 51.)

TEST No. 160A.—4 by 4 ft.; 16-in. wall unplastered; 80 lbs./in.² load; H-shaped 8 by 10¼ by 12 in. side-construction fire-clay tile from source *l*. (Type 16-P–S.)—(This wall was dried to near constant weight before being tested.) No fire effects were noted during the first 8 hrs. of the test. Could not observe exposed side thereafter. 9 hrs. 3 mins.—fire shut off, as the resistance period of the wall, as determined by the temperature rise on the unexposed surface, was obtained at 9 hrs. The load was not increased, as buckling of the top

courses of the wall indicated that failure of the wall was near. (Temperature curves in fig. 181.)

After cooling.—The load was not applied. No fire effects were observed on the unexposed side. Five of the exposed shells in the upper two courses were off. The remainder of the exposed shells were loose and were glazed and warped. The fire damage extended into the wall to a depth of 8 in. All of the unexposed side units were in good condition. (Condition shown in fig. 52.)

TEST No. 161.—4 by 4 ft.; 16-in. wall plastered on both sides with gypsum plaster; 80 lbs./in.² load; H-shaped 8 by 10¼ by 12 in. side-construction fire-clay tile from source *l*. (Type 16–P–S.)—No cracking or other effects were noted during the first 8 hrs., which was the period during which the exposed side could be observed. 11 hrs. 45 mins.—a crack over the horizontal mortar joint 15 in. from top of wall formed on the unexposed side. 14 hrs. 16 mins.—fire shut off, as the resistance period of the wall, as determined by the temperature rise on the unexposed surface, was obtained at 13 hrs. 35 mins. (Temperature curves in fig. 182.)

After cooling.—Wall carried 80 lbs./in.² load, but with a slight additional load failure occurred by crushing of tile in top course. All of the exposed plaster and about one-half of the exposed shells had fused and run off. The remainder of the exposed shells were loose, the damage extending into the wall to a depth of 8 in. All of the units on the unexposed side of the wall were in good condition. (Condition shown in fig. 52.)

TEST No. 162.—4 by 4 ft.; 16-in. wall unplastered; 100 lbs./in.² load; cube-shaped 8 by 8 by 8 in. side-construction fire-clay tile from source *f*. (Type 16–Q–S, fig. 12b.)—No fire effects were noted during the test. 7 hrs. 1 min.—fire shut off. Temperature rise on unexposed side was 86° C. (155° F.). The fire was stopped to obtain the temperature rise after test. (Temperature curves in fig. 183.)

After cooling.—A load of 100 lbs./in.² was applied, which caused failure. In the load failure about two-thirds of the exposed shells came off. The remainder of the exposed shells were loose. The cracking extended into the wall to a depth of 8 in. The units on the unexposed side of the wall were in good condition. (Condition shown in fig. 52.)

TEST No. 163.—4 by 4 ft.; 16-in. wall plastered both sides with gypsum plaster; restrained; cube-shaped 8 by 8 by 8 in. side-construction fire-clay tile from source *f*. (Type 16–Q–S, fig. 12b.)—2 hrs. 20 mins.—first wet spot on unexposed side from steam. No cracks or other fire effects were noted during the test. Could not see exposed side after 8 hrs. 12 hrs. 45 mins.—fire shut off, which was 2 hrs. beyond the resistance period of the wall, as determined by the temperature rise on the unexposed surface. (Temperature curves in fig. 184.)

After cooling.—Two main horizontal cracks extended full length of wall near mid height on unexposed side. Several minor vertical cracks were noted near the top of the unexposed side. All of the exposed plaster was fused, and nearly all of it had run off. Mortar in joints had also run out to maximum depth of 2 in. All exposed shells were in place, except three that were pulled off in moving the wall from the furnace. All of the exposed shells were loose, but no cracks were found back of the first longitudinal web. All other units were in good condition or contained only minor cracks. (Condition shown in fig. 52.)

TEST No. 164.—4 by 4 ft.; 16-in. wall faced with brick and plastered on the tile side with gypsum plaster; 100 lbs./in.² load; 9-cell 12 by 12 by 10½ in. end-construction and L-shaped 12 by 5 by 12 in. side-construction heavy fire-clay tile from source *p*. (Type 16 WYZ–E, fig. 12c.)—The test of this wall with the tile side exposed to the fire was continued for 4 hrs., at which time no fire effects had been noted. The load was increased to 225 lbs./in.² (the capacity of the equipment) without effect. (Temperature curves in fig. 185.)

After cooling.—A load of 225 lbs./in.² was carried without snapping sounds. No fire effects were noted on the unexposed side. All of the plaster on the exposed side was in place but contained fine cracks which, in general, outlined the units. The webs holding the exposed shells were cracked to such an extent that the shells were loose or could be easily pulled off. This damage, however, did not extend beyond the first longitudinal web parallel to the exposed shell. (Condition similar to that of wall 144, shown in fig. 48.)

12. RESULTS OF FIRE AND WATER TESTS

The results of the fire and water tests are given in the log of the tests and in Table 11. The only point that can be brought out in the table is the strength of the masonry after the fire and water tests.

The effects of the fire exposure and of the subsequent application of water are shown in the photographs of Figures 53 to 55, and are described in the log of fire and water tests.

Temperature curves for points in the wall and on the unexposed surface are not given, as the one-hour fire exposure was not long enough to give significant results. The furnace temperatures shown in Figure 186 indicate the severity of the fire exposure given the walls before the water application.

(a) COMPRESSION TESTS OF MASONRY

Each wall contained tile of various designs and constructions which were built in sections so that, after the tests, masonry specimens of each kind of tile could be removed from the wall and tested in compression. Detailed observations of the condition of individual units were not made, but the entire wall was used for the compression tests of the masonry specimens. The main object of this procedure was to determine the load-carrying ability of the walls after the fire and water tests, no load being applied during the test. The strengths of the masonry not exposed to fire, given for the fire and water tests, in Table 11, were obtained from results of compression tests of masonry specimens listed in table 11 in connection with the fire-endurance tests.

(b) LOG OF FIRE AND WATER TESTS

TEST No. 165.—16 by 11 ft.; 8-in. wall unplastered; unrestrained; made up of 12 sections of different kinds of tile, as given in Table 10.

Fire test.—3 to 5 mins.—many snapping sounds were heard. 5 mins.—a vertical crack about 1/16 in. wide appeared on the unexposed surface between sections 3 and 4. 10 mins.—a crack appeared at the top middle of the unexposed side between sections 2 and 3 and extended downward between sections 6 and 7 and 10 and 11, reaching the bottom of the wall at 24 mins. 20 mins.—bottom mortar joint opened on unexposed side. 25 to 30 mins.—a vertical crack following the mortar joints appeared from 1 to 2 ft. from the north end of the unexposed side of the wall, extending from the top to near the bottom of the wall and up to 3/16 in. wide. 33 mins.—tile ridges on section 6 (shale from source *d*) spalling. 20 to 30 mins.—a large amount of steam coming from wall

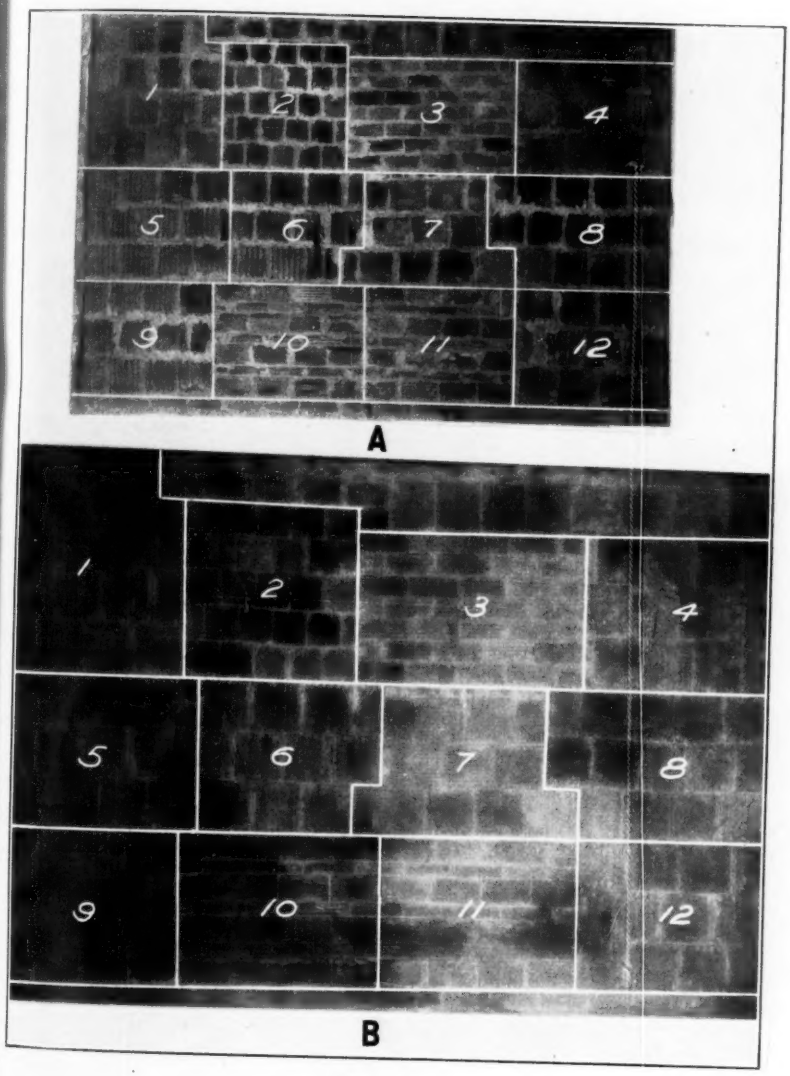


FIG. 53

A, exposed side of wall No. 165 at end of 1-hour fire exposure
B, exposed side of wall No. 165 after application of water

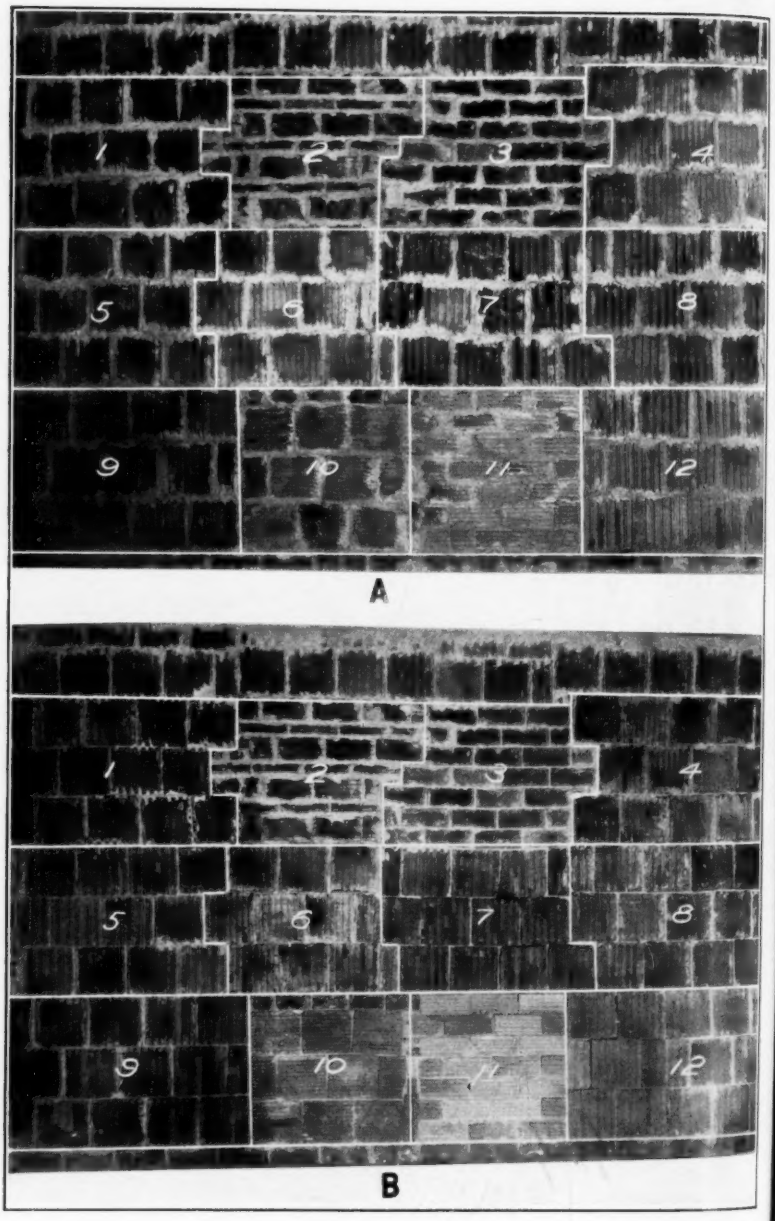


FIG. 54

A, exposed side of wall No. 166 at end of 1-hour fire exposure
B, exposed side of wall No. 166 after water application

60 mins.—fire shut off. Wall withdrawn from furnace. (Temperature curves shown in fig. 186.)

Water test.—61 mins. 18 secs.—water at 30 lbs./in.² nozzle pressure was applied. 64 mins.—until this time it was impossible to see the wall because of the great volume of steam; it was noted that a part of one shell of section 6 was off and that the mortar had been washed from some joints. 65 mins. 42 secs.—water shut off after an application of 4 mins. 24 secs. duration under 30 lbs./in.² nozzle pressure. The duration is equivalent to 2½ mins. per 100 sq. ft. of wall area exposed.

After cooling.—None of the exposed shells were off, except piece of one shell in each of sections 6 and 12. The exposed shells of the shale sections (6 and 10) and one surface-clay section (9) were flaked at some points to the depth of the scoring. The mortar on the exposed side had been washed out of a few of the horizontal joints of the end-construction tiles, especially in section 1. The mortar in some of the horizontal joints of the side-construction tiles of sections 10 and 11 was washed out to depths up to 1½ in. Several vertical joints of the side-construction tiles, especially in sections 10 and 11, were washed away between the exposed shells. As almost all of the wall was used for the masonry compression specimens, detailed examination of the individual tiles could not be made. The greatest loss in masonry strength obtained for the sections in which the horizontal mortar joints had been partly washed away. No compression test could be made of sections 5, 7, and 10, as the masonry specimens were unduly damaged in removing them from the wall. The lowest result obtained was 190 lbs./in.² (The condition of the exposed side of this wall after the fire test and after the water test is shown in fig. 53.)

Test No. 166.—16 by 11 ft.; 8-in. wall unplastered; restrained; made up of sections of different kinds of tile, as given in Table 10.

Fire test.—3 mins.—many snapping sounds were heard, which seemed to come from sections 1, 4, 6, and 7. 20 mins.—the tile ridges on sections 1 and 7 were spalling on the exposed side. 35 mins.—a large volume of steam coming from the wall; no effect was noted on the exposed side except additional spalling of the ridges noted at 20 mins. 60 mins.—fire shut off. Wall withdrawn from furnace. (Temperature curves in fig. 186.)

Water test.—62 mins. 45 secs.—water at 30 lbs./in.² nozzle pressure was applied. 63 mins. 30 secs. to 64 mins. 30 secs.—no water was applied, as a fuse blew in the pump-motor circuit. 66 mins.—pressure suddenly increased to 50 lbs./in.², indicating partial stoppage at nozzle; to maintain test at approximately the same severity the valves in the water line and the pump speed were left unchanged. 68 mins. 9 secs.—water shut off after an application of 4 mins. 24 secs. duration.

After cooling.—All of the exposed shells were in place, except for a part of one shell of section 7. Some of the tile ridges were spalled (secs. 4, 6, 7, 9). A few of the vertical mortar joints of the side-construction tiles and the horizontal mortar joints of the end-construction tiles were washed away between the exposed shells. As almost all of the wall was used for the masonry compression specimens, detailed examination of the individual tiles could not be made. The lowest masonry strength found was 175 lbs./in.² (Condition of the exposed side after the fire test and water test is shown in fig. 54.)

Test No. 167.—16 by 11 ft.; 8-in. wall plastered on the exposed side with two coats of gypsum plaster; restrained; made of sections of different kinds of tile, as shown in Table 10.

Fire test.—9 mins.—some of the plaster in the lower south corner bulging slightly. 16 mins.—the plaster over an area of about 4 sq. ft. of the lower south corner bulging out 4 or 5 in. 17 mins.—the second coat of plaster on the area noted at 16 mins. now off. 28 mins.—about 4 sq. ft. of plaster near the center

of the wall bulging; this fell off at 30 mins. 34 mins.—plaster spalling and buckling at 4 ft. from the bottom and 4 ft. from the north end of the wall. 35 mins.—snapping sounds coming from the wall, apparently from section 6. 60 mins.—fire shut off. Wall withdrawn from furnace. (Temperature curves in fig. 186.)

Water test.—61 mins. 40 secs.—water at a nozzle pressure of 25 to 30 lbs./in.^{2} applied. 62 mins. 30 secs.—the nozzle pressure of the water now at 30 lbs./in.^{2} which was maintained during the remainder of the application. 63 mins. 10 secs.—nearly all of the plaster, except at the top of the wall, now off. 66 mins. 4 secs.—water shut off after application of 4 mins. 24 secs. duration.

After cooling.—Only a small amount of the first, or base, coat of the plaster, totaling approximately 5 sq. ft., was in place. This was near the top of the wall. None of the shells were off. None of the mortar joints had been washed out. Only a few of the exposed shells were spalled, the spalls extending the depth of the scoring and occurring on the hard-burned or laminated tiles of sections 5, 6, and 12. As the whole wall was cut up into masonry compression specimens, detailed examination of the individual tiles could not be made. The lowest masonry strength obtained was 205 lbs./in.^{2} (Condition similar to wall 168, shown in fig. 55, only that less plaster remained in place on wall 167.)

Test No. 168.—16 by 11 ft.; 12-in. wall plastered on exposed side with 2 coats of cement plaster, which gave a total thickness of approximately $\frac{7}{8}$ in.; unrestrained; made up of 12 sections, as given in Table 10.

Fire test.—6 mins.—snapping sounds were heard as though plaster was coming off; the exposed side of the wall could not be observed at this time. 12 mins.—about 3 sq. ft. of plaster near the middle of the wall now off; small patches of plaster were observed to be off other places. 15 mins.—an inclined crack, following mortar joints, appeared on the unexposed surface of the wall in middle portion for full height of wall. 20 mins.—many snapping sounds were heard. 40 mins.—crack noted at 15 mins. now opened to $\frac{1}{4}$ in. width at top; this opened farther, until at 55 mins. it was approximately $\frac{1}{2}$ in. wide on the unexposed side. 60 mins.—fire shut off. Wall withdrawn from furnace. About 7 sq. ft. of the plaster had fallen from the north middle portion of the exposed side. The remainder of the plaster appeared to be in good condition. (Temperature curves in fig. 186.)

Water test.—62 mins. 25 secs.—water under nozzle pressure of 42 lbs./in.^{2} was applied. 64 mins.—one-half of the plaster, mostly in the lower portion of the wall, was off. 65 mins.—the water pressure was increased to 50 lbs./in.^{2}; this was further increased to 55 lbs./in.^{2} at 66 mins. 66 mins. 20 secs.—water off, due to fuse breaking pump-motor circuit. 67 mins. 30 secs.—water at 42 lbs./in.^{2} was applied; this was increased to 55 lbs./in.^{2} in a short time. 68 mins. 45 secs.—water was off, due to fuse breaking pump-motor circuit. 69 mins. 40 secs.—water at 55 lbs./in.^{2} nozzle pressure again applied. 72 mins.—about 60 per cent of the plaster now off. 72 mins. 55 secs.—water shut off after an application of $8\frac{1}{3}$ mins., at an average nozzle pressure of 50 lbs./in.^{2} The duration is equivalent very nearly to 5 mins. per 100 sq. ft. of wall surface exposed.

After cooling.—The plaster in the lower six courses of the north end of the wall was off, except for small patches of the first coat. The horizontal mortar joints in this portion of the wall were washed out in four places between exposed shells. The vertical mortar joints were washed out in three places to a depth of 3 in. The plaster on the south end of the wall was off entirely only on the two lower courses. Patches of the second coat in the upper portion of the wall were also off. The mortar joints at a few points in this portion of the wall were washed out to a depth of 1 in. Hole from spalling in exposed shell of one shale tile in section 10. A few shells in another section (11) were also spalled to the depth of the

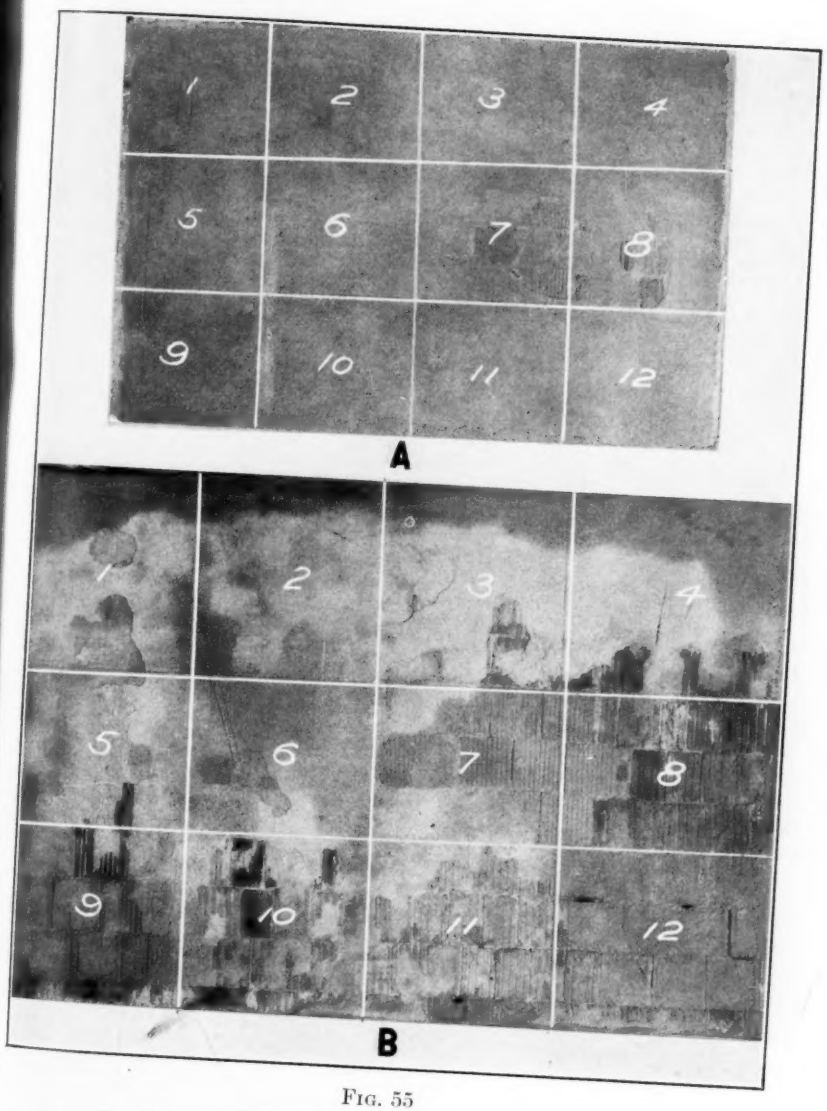


FIG. 55

A, exposed side of wall No. 168 at end of 1-hour fire exposure
B, exposed side of wall No. 168 after water application

scoring. As all of the wall was cut up into masonry compression specimens, detailed examination of the individual tiles could not be made. The masonry strength, as indicated by tests of the specimens, varied from 95 to 485 lbs./in.^{2}, the lower value being for section 2, a 2-unit construction which had been protected by the plaster throughout the test. A masonry specimen of tile from this same source built up in the same way, but not exposed to fire, had a strength of 320 lbs./in.^{2} It is probable that the low value obtained for the fire-exposed specimen was due to damage sustained by it in removing it from the wall. This is further indicated by the result of compression test from section 11 of the same kind of tile but built as a single-unit wall. While directly exposed to the hose stream, due to spalling of plaster, it developed a strength of 255 lbs./in.^{2} Exclusive of section 2, the lowest compressive strength obtained was 145 lbs./in.^{2} from section 7. This was also damaged in removing it from the wall. The companion specimen, No. 9, developed compressive strength of 340 lbs./in.^{2} (The condition of this wall after the fire exposure and after the water test is shown in fig. 55.)

13. SUMMARY AND DISCUSSION OF RESULTS

The interpretation and discussion of the results of the fire tests will be based (1) on the ability of the walls to safely carry working loads during and after fire exposures; (2) the ability of the walls to prevent the transmission of flame, hot gases, and high temperatures to the unexposed side; and (3) on the damage to the masonry and individual units. The first two considerations are of prime importance from the standpoint of the building where the fire originates, the adjacent construction, and general community protection. The damage to the construction is of interest, as it concerns possibility of reuse after the fire and of the ease and practicability of making repairs.

(a) DAMAGE TO THE CONSTRUCTION

The fire damage to the individual units varies greatly in amount, depending upon the characteristics of the clay, the hardness of burning, the design of the units, the loads applied or stresses induced during the fire exposure, the wall construction, and presence and type of plaster, or furring and plaster. The damage is caused by unequal expansion of integral parts of the unit, which results from rapid heating of one side of the wall. This sets up shearing stresses that decrease in intensity beyond a certain distance from the exposed surface. The stresses are relieved either by rupture of the body or, if it has a sufficiently low modulus of elasticity and high tensile strength, by yielding along the lines of stress. In bodies that are decidedly laminated or have a high modulus of elasticity, rupture near the surface of the exposed shell takes place in the form of flaking and spalling. In most cases, however, the damage occurs in the transverse webs, which have a much smaller sectional area parallel with the shell than the shell itself. If the unit is laminated, the fracture in the webs is parallel to the exposed surface, occurring along lamination planes. The fracture is generally ragged, so that the

shells remain in place. If the unit is not laminated, the fracture of the webs will tend to follow the lines of maximum stress which are inclined to the surface. With such fractures the part of the web attached to the exposed shell and projecting into the wall will generally tie the shell to the wall sufficiently to allow it to continue to give protection. Where in the manufacturing process the bridges holding the cores of hollow-tile dies are placed parallel to the faces of the tile exposed in the wall, the column of clay from which the transverse webs are formed is cut, and if the cuts do not heal thoroughly after passing the bridge, the fracture of the webs usually occurs here. When the fracture occurs in these places there is no projection into the wall to hold the loosened shell in place. Since most of the tile for these tests were molded with bridges so placed whatever effect it has on performance in fire tests was obtained.

(1) Effect of Type of Clay and Burning.—It is apparent from the above description of the usual fractures that the physical characteristics of the tile, such as texture, strength, modulus of elasticity, and coefficient of expansion, all of which depend upon the type of clay and burning, govern to a considerable extent the damage to the individual units. Some of the surface clays and open-burning fire clays were laminated, so that the first fire effects consisted of flaking and spalling from the exposed surface. This is shown in the photograph of the exposed side of wall No. 47 (fig. 29) and wall No. 69 (fig. 35). With such walls further fire effects consisted of a ragged fracture of the webs, so that the shells were held in place during the fire exposure. Flaking and spalling were also observed with some of the very hard burned tiles which were practically free from laminations. This is shown in the photographs of the exposed side of walls 4 and 9 (figs. 22 and 24), respectively. This effect is especially shown with wall No. 9, in which the very hard vitrified tiles spalled decidedly, throwing the plaster off. The spalling consisted of continual flaking until, in four tests (Nos. 4, 8, 9, and 15) it has penetrated through the wall to the unexposed surface. This determined the fire-resistance period for wall No. 4. It can be seen from the photographs that extensive spalling was confined to individual units, while the surrounding units were not affected. This indicates that tile that are burned very hard or are vitrified are more susceptible to damage than normally burned tile.

The usual fire damage to tile consists of fracture of the transverse webs. In these cases the fracture follows the lines of greatest stress which are inclined to the face of the tile, and portions of the webs are usually left on the loosened shell that tie it to the undamaged portion of the wall. This is shown by the photographs of the exposed side of walls 115, 130, and 134 (figs. 44 and 47), one photograph in each case being made after the fire exposure and the other after the loosened shells had been removed.

(2) Effect of Number of Cells, Webs, and Units.—The number of cells through the thickness of the wall does not decrease the damage from flaking and spalling of the exposed shells or the fracture of the webs holding the exposed shell, if the tile is made of clay for which such fire effects obtain. The number of cells, however, does influence the extent of the resulting damage to the wall. The webs holding the exposed shells are the first to crack. With longer fire exposures the transverse webs back of the first longitudinal webs are cracked for tile of some clays. In this way the extent of the damage or its penetration into the wall is dependent upon the number of cells through the thickness of the wall. If the first series of cells near the exposed surface are small and the number of transverse webs attached to the outer shell are not greater in number or combined thickness than the interior transverse webs, the damage with most exposures will be confined to the exposed shell and attached short webs (sketch B, fig. 11). This was the case with the double-shell tile of walls 89 and 90 (fig. 39). With these walls the fracture occurred in the short transverse webs between the inner and outer shell and loosened some of the outer exposed shells. After the fire such shells could be removed and reset with mortar and the wall replastered. If all of the outer shells were loosened, they could be removed and the wall repaired with a heavy coat of cement plaster. If the short webs between the inner and outer shells of double-shell tiles are greater in number or combined thickness than the long transverse webs holding the inner shell, the fracture will occur in the long webs, so that the double shell will be of no value in localizing the fire damage. Tests 91, 92, and 93 were made to study this feature. The general location of the cracks formed by the fire exposure are shown by the sketch A (fig. 11). The effect of the double shell has been discussed in greater detail in Section III, 4 (*e*), page 40.

The extent of the damage to 3-cell 8 by 5 by 12 inch (back-up) tile is also less than that for a similar exposure for 2-cell 8 by 5 by 12 inch tile, since for fire exposures corresponding to the resistance period of 8-inch walls the damage does not generally extend beyond the first cell.

With multiple-unit walls (figs. 12a and 12b) the damage is confined to the units on the exposed side, except with fires of very long duration. Fires of intensity and duration equivalent to four hours or more of the standard fire-test exposure may damage some of the unexposed units of 2-unit unplastered walls. If such walls were plastered with gypsum or cement plaster, exposures equivalent to 8 to 10 hours of the standard test fire would be required to cause cracking of the webs of the unexposed units.

(3) Effect of Wall Openings.—Tile near openings, such as doors and windows through which flame may pass, are liable to be damaged

more than those in the face of the wall. This is due to the fact that tile at the openings are exposed to fire over their whole thickness as well as on the face, and the consequent greater expansion induces stress concentrations in the wall near the openings. An example of this is shown by wall No. 3 (fig. 21). This was a loaded wall for which the openings at the end had not been effectively stopped prior to the test. The extent of the damage to this wall is probably greater than would generally occur at openings, since the tile used in this test usually show decided fire effects.

(4) SIZE OF UNIT.—Decreasing the length of the unit, such as by cutting 8 by 12 by 12 inch units to 8 by 12 by 6 inches, does not change the fire effects, as it concerns the webs holding the exposed shells. Several tests (Nos. 91, 92, and 93), for which units of 5-inch length were built adjacent to units of 10-inch length, were made to study the effect of length. In dismantling these walls, it was found that the short units were substantially in the same condition as the longer ones.

A decrease in the thickness of the units, however, causes a considerable decrease in the susceptibility to cracking of the transverse webs. This is shown by the tests of walls 151 and 152, these being 2-unit walls, tile in alternate courses on the exposed side being 8 by 12 by 12 inch and 3¾ by 12 by 12 inch units. In both of these tests a larger percentage of the 3¾-inch than of the 8-inch tiles were undamaged. This effect is also shown by the test of wall No. 146, a brick-faced wall backed with 2-cell 8 by 5 by 12 inch and 3¾ by 5 by 12 inch 1-cell tile, every third course being of the 3¾-inch thick units, the thin side being exposed to the fire. Only 4 per cent of the 8 by 5 by 12 inch units were undamaged, while 58 per cent of the 3¾ by 5 by 12 inch units were in good condition.

(5) DESIGN OF UNIT.—The shape of the unit was found to have at most only a minor effect upon the susceptibility to cracking of the transverse webs or shells holding the exposed shells. However, tiles of some side-construction designs show fire effects in the form of vertical cracks, usually in line with the vertical mortar joints above and below the unit and extending through it, thus dividing it into two approximately equal lengths. This occurs with the units that, as laid in the wall, have short vertical dimensions as compared with the horizontal dimensions. This is illustrated in the views of the exposed side of walls 20, 26, 62, 63, and 65 (figs. 25, 26, and 32).

(6) EFFECT OF PLASTER.—Portland cement plaster applied on a few of the walls stayed in place throughout the fire exposure in all tests. It was dehydrated by fires of six hours' duration, so it could be easily removed. In cooling, fine cracks, generally outlining the units, were formed, as is shown on the exposed side of wall No. 48 (fig. 29). If the exposure is of high intensity, fusion of the plaster

begins. It is very difficult to remove cement plaster which has begun to fuse.

Gypsum plaster of good grade stayed in place on all walls on which it had thoroughly set. Much of the plaster obtained on the open market had a long time of set, 20 hours or more. Some of the plaster dried out before setting, in which case it often fell off after short fire exposure, as for walls 29, 30, 88, 96, and 98, as shown in Figures 26, 38, and 40. Attempts were made to prevent the drying out by sprinkling the walls or blanketing them with wet burlap, which, however, for plasters that had a time of set of over 30 hours, were not successful. In nearly all cases where the plaster fell off its failure could be traced to the drying out of the plaster, caused by dry room conditions, unduly long time of set, or low gypsum content of the plaster.[28]

The gypsum plaster was calcined by the fire exposure, so that when cool it could be readily washed off with a small hose stream, as shown for wall No. 90, in Figure 39. Unless fusion of the gypsum plaster had started, it always showed fine shrinkage cracks after the fire and some large cracks which outlined the tile units. When the fire exposures were continued for long periods and consequently high temperatures were reached, the gypsum plaster fused and sloughed away, as is shown for walls 154, 158, and 163 (figs. 50, 51, and 52.) With tests of these long durations it was not possible to observe the exposed side to determine the time when the gypsum plaster began to fuse. The plaster had just begun to fuse on wall No. 154, which was subjected to fire for 9 hours and 24 minutes with furnace temperatures at the end near 1,315° C. (2,400° F.). This gives an indication of the temperatures at which gypsum-silica sand plaster begins to fuse.

Lime plaster fell off all the walls on which it was used after fire exposure of from 3 to 8 minutes where aged for 10 to 12 weeks. The condition of such walls after fire is shown for walls 50 and 54 in Figures 29 and 30. Although these walls were aged for longer periods than walls plastered with other materials, it was thought that better results would be obtained after aging for still longer periods. Wall 55 was, accordingly, plastered and aged 384 days before testing. The plaster on this wall stayed in place during fire exposure for 11 minutes, when it began to buckle, over one-half of it falling off within 15 minutes (fig. 30).

To determine the effect of lime additions to Portland cement plaster, tests were made of walls 51, 52, and 53, plastered with cement-lime plasters of 1:½:4, 1:1:5, and 1:2:7 volume parts of cement, hydrated lime, and sand, respectively. These plasters were weaker

[28] Since these tests were made, Federal and A. S. T. M. specifications for neat gypsum plaster have been revised to include a time of set requirement and increased calcined gypsum ($CaSO_4.\frac{1}{2}H_2O$) content.

after comparable fire exposures and more easily removed than the 1:3 Portland cement plaster. As shown in Figures 29 and 30, only the plaster having a greater lime than cement content fell off during the test. From this it appears that the volume ratio of lime to cement for such plasters should not be greater than unity if good fire-resistive properties are to obtain.

For some of the early tests the white or finish coat, which usually consists of equal parts of lime and calcined gypsum, was applied in addition to the two body coats. In all cases the white coat peeled and generally came off, as is shown for walls 58, 59, and 84 (figs. 30 and 37). The white coat was not applied for subsequent tests, as it was thought that nearly equivalent performance could be obtained by floating and troweling the brown coat.

When the plaster came off during the early part of the test, the wall was usually damaged more than it would have been had no plaster been used. This was the case with wall No. 50, as can be seen by comparing its test log and photograph with those of wall No. 47, an identical wall which had not been plastered.

Where the plaster stays in place throughout the fire exposure, more especially during the time of rapid temperature rise, the damage to the tile is greatly decreased, and in many cases for short fire exposures no damage is incurred. Reference here can be made to the one and one-half-hour fire tests of walls 11 and 12 and 47 and 49, in which the majority of the exposed shells of the unplastered walls were loosened, while the damage to the plastered walls was much less pronounced. Another example of this can be cited in the six-hour fire exposure of walls 89 and 90 (fig. 39), in which nearly all of the exposed shells of the unplastered wall were loose and less than one-half of the units in the plastered wall were damaged. With comparable walls, 79 and 80, subjected to a fire exposure of two hours, the number of exposed shells loosened on the plastered wall is small, while about 70 per cent of those on the unplastered wall were loose. With walls 38 and 39, built of tile which generally show decided fire effects and tested to 3 hours and 31 minutes, the difference, while smaller, is still in favor of the plastered wall. Another example is the six-hour test of walls 69 and 70 where the difference is small, but in favor of the plastered wall.

Comparable tests wherein both cement and gypsum plasters were used were made with walls 77 and 78 and walls 85 and 86. The difference in the number of units undamaged, while small, is in favor of the wall covered with gypsum plaster.

Three walls, 13, 14, and 88, were furred on the exposed side with 2 by 12 by 12 inch split furring tile and plastered. Although these walls were subjected to fire exposures of three and a half to six hours, none of the units were damaged. Generally the furring tile were not

damaged, although the plaster and mortar were calcined so that the nails holding them were loosened. However, the furring stayed in place throughout the fire exposure. The condition of walls 14 and 88 after test is shown in Figures 25 and 38. Even after severe fires such a wall could be restored to perfect condition by resetting or replacing the furring tile and replastering.

Without the furring, plaster alone that remains in place gives protection against all damage to the wall during the initial part of the fire exposure. The length of this period was not directly determined in the tests, but it was apparently less than one hour for some kinds of tile, since damage was incurred in test No. 145 that was terminated at one hour, and damage was apparent in a number of tests terminated at 1 hour 30 minutes. In others terminated at this period the damage was very minor. Since for hard tile, and to a less degree for softer tile, fracture of shells and webs is accompanied by distinct snapping sounds, these may serve to indicate the time of initial damage. The best estimate that can be made from evidence of this kind noted in the test logs (see log of tests 12, 15, 25, 36, 37, 52, 58, 68, 87, and 136) is that plaster gives full protection during the first 15 minutes for tile most susceptible to fire damage. For tile less subject to fire effects the period of full protection afforded by plaster is longer, but no quantitative results can be given other than as indicated in the tests stopped at 1 hour 30 minutes (see log of tests 48, 49, 51, 52, 56, 58, 59, and 84).

(7) Effect of Load and Restraint.—The amount of load applied or induced during the fire has some influence on the fire effects on individual units and the probability of loosened exposed shells staying in place. Individual tiles in unrestrained walls will not be damaged as much as those in loaded or restrained walls. This is illustrated in the tests of walls 42 and 43, the first of which tested unrestrained had 28 per cent of the exposed shells loosened, and the second, tested under load of 120 lbs./in.^{2} of gross bearing area, had all exposed shells loosened. Further information may be obtained from a comparison of walls 67 and 71.

Where the wall was restrained by the test frames, it would take on an indeterminate load from expansion, and more of the loosened shells came off than from unrestrained walls or those carrying definite loads. This is shown in the test of walls 74 and 76 (fig. 35), the former being tested under a load of 120 lbs./in.^{2} and the latter restrained. Some of the exposed shells fell off the restrained wall after an exposure of about the same duration as that to which the loaded wall was subjected, no shells falling off the latter. The same effect was present in tests of walls 79 and 81 (figs. 36 and 37), some of the shells of the restrained wall falling off after the end of the test and all of the shells of the loaded wall staying in place.

Although no difference could be noted in the amount of cracking or loosening of the exposed shells between walls tested under different loads, the amount of load did affect the ability of the loosened shells to stay in place during the test. This is illustrated in the tests of walls 34 and 38, which were identical in all respects except for the load. The shells of the former wall, which carried 120 lbs./in.^{2} load, came off early during the test, and the wall failed after 45 minutes of fire exposure. The latter wall carried 70 lbs./in.^{2} load throughout a fire exposure of 3 hours 31 minutes without falling of shells. A similar illustration is obtained from comparison of walls Nos. 3 and 4.

(b) LOAD-CARRYING ABILITY

The ability of tile walls to carry load under fire exposures is governed by the initial strength of the wall and the amount of fire damage incurred. With the exception of the eight walls listed in Table 18, all of the walls in this series carried the working load applied during the fire tests up to or beyond the time required to reach the limiting temperature rise on the unexposed side.

Wall No. 17, built of 3-cell side-construction shale tile made from shale *c*, failed under load of 95 lbs./in.^{2} after fire exposure of 1 hour 32 minutes in the small furnace, which was about one-half hour below the resistance period developed by comparable tile on the basis of temperature transmission. The exposed shells were loosened by the fire, although remaining in place until failure occurred. No further tests could be arranged with tile from this source, but side-construction, 3-cell H-shaped tile from source *c–1*, adjacent to *c* and using clay from the same formation, were included in this series (Nos. 22 and 23) and also in the combustible filler series (Sec. III, p. 36). Judging from strength and absorption data, the tile from *c–1* were not burned as hard as those for wall No. 17. Four of these walls supported load of 80 lbs./in.^{2} up to the end of 6-hour fire tests, the wall of tile with 15 per cent filler failing under load at 3 hours 40 minutes.

Wall No. 32, of surface-clay tile with high flux content, failed under load of 120 lbs./in.^{2} after 1 hour 37 minutes fire exposure in the small furnace. Walls 34 and 35, made of lighter tile from the same source but of 9-cell design and laid up, one with cement-lime and the other with cement mortar, were tested as companion walls in the large furnace and failed at 45 minutes under load of 120 lbs./in.^{2}. To determine the effect of decrease in working load, wall No. 38, of the same kind of tile as walls 34 and 35, was laid up in cement-lime mortar, and as tested in the large furnace under load of 70 lbs./in.^{2} readily carried this load for the period (3 hours 27 minutes) required for the average temperature rise of 139° C. (250° F.) to obtain on the unexposed side. Wall No. 119 was a 12-inch wall, built of the same kind of tile as walls 34 and 35 by setting the tile with the 12-inch dimension perpendicular

TABLE 18.—*Walls whose fire-resistance periods were determined by load-carrying ability*

No.	Wall			Tile				Mortar	Plaster	Load	Time of failure
	Thickness	Height	Width	Construction	Source	Design	Size (inches)				
	Inch	*Feet*	*Feet*							*lbs./in.²*	*Hr. min.*
17	8	4	4	Side	c	K	8 by 5 by 12	Cement-lime	None	95	1 32
32	8	4	4	End	j	A	8 by 12 by 12	do	do	120	1 37
34	8	10½	8	do	j	C	do	do	do	120	45
35	8	10½	8	do	j	C	do	Cement	do	120	45
40	8	4	4	do	f	A	do	Cement-lime	do	120	27
119	12	4	4	do	j	C	do	do	do	120	4 10
123 [1]	12	10½	8	do	j	C	3¾ by 12 by 12	do	do	80	2 22
						H	8 by 5 by 12				
158	16	4	4	Side	m	K	8 by 5 by 12	do	Gypsum both sides	80	12 33
						M	3¾ by 5 by 12				

[1] This was the second fire test of this wall. See log of the test.

to the surface. This failed under a load of 120 lbs./in.^{2} after 4 hours 10 minutes fire test in the small furnace, which is a little below the fire-resistance period as determined by temperature transmission with this design of tile, but above that obtained on this basis with other designs. In a test (No. 121) of a 2-unit 12-inch wall of tile from the same source, failure under load of 120 lbs./in.^{2} occurred at 5 hours 50 minutes. No small pads were placed on this wall, but temperature measurements on the free surface indicated that the fire-resistance period as based on the 139° C. (250° F.) average temperature under the pads had been attained. A test (No. 123) of a similar wall was made in the large furnace, but the filler tile at the top of the panel were improperly bedded, and at 38 minutes the load had to be taken off, although the fire exposure was continued at reduced intensity for a total of 5 hours 4 minutes in order to complete the test on the companion wall. In the final fire test wall No. 123 carried working load of 80 lbs./in.^{2} for 2 hours 22 minutes. This is considerably below the fire-resistance period as determined by temperature rise on the unexposed surface, but, considering that the wall had been previously subjected to fire, the results can not be considered fully valid. As material could not be obtained for another test in the large furnace, a test of an identical construction (wall No. 120) was made in the small furnace in which a load of 80 lbs./in.^{2} was satisfactorily carried for the 5-hour 18-minute resistance period of the wall, determined by the 180.6° C. (325° F.) maximum temperature rise at one point.

Wall No. 40 (Table 18), of 8 by 12 by 12 inch tile made of clay consisting of a mixture of pottery clay, fire clay, and fire sand, high in silica content (Table 1) and tested in the small furnace, failed under load of 120 lbs./in.^{2} at 27 minutes. The companion wall, No. 41, carried the load to the end of the one and one-half hour limit set for the test, although much weakened by the fire. Walls of tile of comparable design from the same source were not subsequently tested, but Nos. 65 and 66, of T-shaped tile from the same source but of clay of lower silica and higher alumina content and well burned (the absorption was about 50 per cent of that for the tile in walls 40 and 41; see Table 14, source *r*) were tested in the small furnace. No. 65 sustained load of 80 lbs./in.^{2} to the end of a six-hour test period. The test of No. 66 was stopped at 45 minutes to determine the effects on the tile units of a fire of short duration.

All of the above walls that failed under load were not plastered. The only load failure of a plastered wall was with No. 158, a 16-inch side-construction wall which failed under load of 80 lbs./in.^{2} at 12 hours 33 minutes, or about 19 minutes before the fire-resistance period, as based on temperature rise, was reached. Considering this small difference and the long resistance period developed, the load failure in this case is not considered serious.

In one test in the small furnace of an 8-inch unplastered wall of 8 by 12 by 12 inch shale tile from source *d*, failure occurred under load of 120 lbs./in.^{2} at 20 minutes. Spalling of part of a shell occurred at the beginning of the test on applying the load due to a high bearing point between the upper two courses. The results of this test are not included, as the short specimen did not give the opportunity for equalization of stress concentrations that is afforded by a wall of story height.

In the tests made to determine effect of grog and combustible fillers described in Section III of this paper, a few failures under load occurred, but the tile were made of experimental mixtures of clay and fillers, hence the results would not apply for tile as regularly manufactured.

Like the damage to the individual units, the load-carrying ability varies with the kind of clay used for the tile, the design of the latter, the construction used, and whether plaster is applied.

(1) Type of Clay.—Shale and the hard-burning fire clays give units of high strength and, if properly bedded, walls initially somewhat higher in strength than those from less dense tile. The individual units, especially those of shale, are, however, liable to be considerably damaged by even short fire exposures. Tile made from open-burning fire clays and most surface clays do not generally have as high initial strength but suffer less from fire exposure, and, in cases where the webs crack, the fracture is usually ragged, so that the shells remain in place and help to carry the load. Also, on account of the lower strength of the material, these tile have thicker shells, whereby a better mortar bed for end-construction tile is obtainable. Surface clays having a high lime or general flux content, in addition to being low in compressive strength, also have high coefficients of expansion, so that the webs are more likely to fracture. When such walls are under high loads the loosened shells are thrown off and the wall may fail to carry the working load. With lower loads the shells would be less likely to be thrown off and the wall strength less impaired.

As it concerns shales and surface clays, the lime-magnesia content appears to be a governing element in determining the amount of fire damage and ability to carry load. This is attributable to the glass-forming properties of these compounds at the temperature at which the burning is finished. To judge from the analyses of clays represented in these tests, tile of clays having a high lime-magnesia content will suffer severe fire damage, although for tile of intial high strength or of favorable design of unit, working load as high as 120 lbs./in.^{2} will be supported up to or beyond the time when limiting temperatures obtain on the unexposed side. For clays of a semi-refractory nature, such as that from source *r* in the present series,

the total silica apparently has some bearing on the effects of fire exposure, tile from clays high in SiO_2 being more subject to cracking than those lower in silica content. Within the range from 2 to 6 per cent in which the combined alkalies (Na_2O, K_2O) were present in the clays represented, they appear to have no decided effects on the fire-resistive properties of the tile.

It will be noted in Table 18 that, except for wall 123, which had been subjected to a previous fire test, and No. 158, a 16-inch plastered wall failing under load at 12 hours 33 minutes, the loads at failure were in excess of the 80 lbs./in.^{2} later in this report recommended as a working-load limit. Retests at lower loads of walls failing under the 120 lbs./in.^{2} load indicated in several cases ability to sustain such lower loads for periods equal to those required for the limiting temperatures to obtain on the unexposed side. Hence, load-carrying ability at load of 80 lbs./in.^{2} can be premised for some of the wall constructions that failed under the 120 lbs./in.^{2} load generally applied on end-construction tile in these fire tests.

(2) Design.—The design of the unit affects the load-carrying ability in that it governs the extent of the damage to the individual units. With the double-shell tile or with the units having three or more cells through an 8-inch thickness instead of two, a smaller portion of the wall is damaged by the loosening of the exposed shells, leaving the wall better able to carry the load. The length of the bond or overlap between adjacent units in the same course further affects the load-carrying ability, especially where there are openings in the wall. This is illustrated by the tests of the 12-inch walls built of 8 by 12 by 12 inch tile set with the 12-inch dimension perpendicular to the surface of the wall. With these walls a bond of between 3 and 4 inches is obtained instead of the usual 5 or 6 inches. With the shorter bond the adjacent units have less resistance against sidewise movement toward the opening, which, if it takes place, decreases the load-carrying ability of the wall. This is illustrated by wall No. 114 (fig. 44).

(3) Mortar.—Although several tests of comparable walls laid up with cement mortar and cement-lime mortars were made, no appreciable effect of this mortar variation could be noted in the fire effects on the individual units or the load-carrying ability of the walls.

(4) Plaster.—Plaster increases the ability to carry load under fire exposure in that it decreases the fire effects on the tile units and, to some extent, on the mortar bed. For tests of long duration the latter would be weakened sufficiently to appreciably decrease the load-carrying ability of the wall irrespective of the condition of the tile, although in the tests no failure could be attributed directly to this cause. With the exception of 16-inch wall No. 158, which failed under load only 19 minutes before a resistance period of 12

hours 52 minutes, as determined by temperature transmission, was developed, no plastered wall failed under working load before the limit set by the temperature rise on the unexposed side.

(5) Strength of Masonry.—For 48 walls for which compression tests of masonry specimens unexposed to fire, or cut from the walls after fire-endurance tests, are listed in Table 11, the average strength of the unexposed specimens is 444 lbs./in.^{2} and of the fire-exposed masonry 255 lbs./in.^{2}. As previously indicated (Sec. 11, *h*, p. 99), the values for the unexposed masonry may be somewhat lower than if the specimens had been of greater height, and the same consideration will also apply for the fire-tested masonry. The strength of the masonry was also affected by damage incurred in cutting it out of the wall and mounting it in the testing machine. On the other hand, it can not be premised that the weakest part of the tested wall, where failure in loading the whole wall would have occurred, was always included in the specimen taken. While variations due to these conditions may be large for individual tests, the average for the whole number made or groups thereof can be taken to give an approximate measure of the percentage loss in strength from the fire exposure. The average loss for the 48 comparisons made was 41 per cent, the maximum in any one test being 72 per cent. Three tests of fire-exposed specimens gave higher values than the comparable unexposed specimens, but the difference was within the experimental variations that are to be expected.

Indications of the strength of walls were also obtained from the excess loads applied to most of the walls tested under working loads, both at the end of the fire test and after cooling (see test logs and Table 15). Some walls failed under only small additional load, others carried from 50 to 100 per cent in excess of that carried during the fire test without failure. The masonry was apparently weaker after cooling than at the end of the fire exposure, due possibly to cracking developed by the temperature differences existing between different depths in the wall during the cooling period, and the further progress of high temperature and dehydration of mortar toward the unexposed side.

(c) EXPANSION AND DEFLECTION

The expansion, in inches per foot of height, is shown for typical walls, tested in the small furnace, in Figure 19a. It is seen that the maximum for walls of hard tile corresponds to a vertical expansion of a 10-foot high wall of about ½ inch. This was checked approximately by observations of the movement during test of the loading beams for the tests in the large furnace. Walls of side-construction tile expand less than the end-construction tiles, due, apparently, to a greater number of mortar joints, whose shrinkage counteracts the expansion of the clay units. Walls of soft tile expand less when

heated under load than those of harder tile and reach their point of maximum expansion sooner.

The deflection of the walls is a function of the temperature difference between the two sides of the wall, the lateral dimensions, the thickness, and the coefficient of expansion of the wall. The latter varies with the tile clay, with the number and strength of the mortar joints, and with the load. The deflections of typical large restrained, loaded, and unrestrained walls are shown in Figures 19b and 19c, and the maximum deflections are given in Table 16. As shown by the curves, the deflection of the unrestrained walls was away from the fire and attained maximums from 3.1 to 5.7 inches at the top of 8-inch walls and 3.7 to 6.7 inches at the top of 12 and 16 inch walls. The lower deflection of the 8-inch walls was caused by the bracing afforded by the pilasters built into the ends of the test walls in order to avoid extreme test conditions. In cooling, all of the test walls returned to within 2.6 inches of their original positions. The deflection of the restrained or loaded walls was toward the fire, being maximum at the center of the wall. For 8-inch walls the maximum deflection at this point during the fire varied from 0.6 to 1.6 inches, and in cooling they returned to within 0.6 inch from the original undeflected position. The amount of deflection decreased with increased wall thickness, being for 12-inch walls from 0.2 to 0.9 inch, with recovery after the fire to within 0.7 inch from the original position. No considerable difference in deflection between the restrained and the loaded walls was noted, which indicates that the deflection is caused more by the temperature difference between the two surfaces of the wall than by general expansion and bulging of the wall from the restraint within the frames containing them.

(d) REPAIR OF FIRE-DAMAGED WALLS

The practicability of repairing walls which have passed through fire exposures depends upon the amount of damage incurred. For plastered walls which have been subjected to short fires without cracking of webs or loosening of shells, repairs can usually be made by replastering. As the structural part of furred walls is damaged only by very long fire durations, repairs can generally be made by resetting the furring and replastering. Plastered walls for which the double-shell design is used can usually be repaired by removing the outer shells of damaged tile and filling the spaces thus formed with a strong cement mortar before replastering. In cases where only occasional outer shells of double-shell units are loosened they can be reset satisfactorily by bedding in a rich mortar. Where sections of end construction walls are damaged by cracking of the transverse webs, if the exposed shells remain in place, satisfactory repairs can be made by removing a few of the exposed shells near the top of

the damaged section and filling the cells near the exposed side with a mortar of fluid consistency and replastering. If such damaged sections are thoroughly wetted before filling, the mortar can be expected to run down into the wall for several courses and fill the cells. Three walls of dense-burned tile, Nos. 4, 9, and 15, which had been exposed to severe fires, and in which the transverse webs holding the exposed shells were generally cracked, were repaired and subjected to a second fire exposure. The method of repairing the first of these walls was modified slightly from that described above in that the shells of every third course were removed and the cells were filled and the plaster applied with the "cement gun." [29] The condition of the exposed surface of this wall before and after the second fire exposure is shown in Figure 22. During the second test of this wall (No. 5) the "gunite" plaster spalled and exposed the shells of some of the tile. This was probably due to the high water content of the gunite and cement filling, as the wall had aged only a short time after it had been repaired before it was tested. However, the repaired wall carried the load during the second test and kept the temperture on the unexposed surface lower than the original wall.

The other walls were repaired by pouring mortar of a fluid consistency into the cells from near the top of the wall and replastering the exposed side. These walls also carried the load and kept the temperature on the unexposed surface lower than the original walls, the temperature rise being retarded by the greater mass and water content of the repaired walls. The condition of the exposed side of these walls (Nos. 9 and 15) before being repaired and after being repaired and tested as walls 10 and 16, is shown in Figure 24. It is seen that the plaster stayed in place throughout the second fire exposure.

(e) FIRE AND WATER TESTS

Although only four walls—two plastered and two unplastered—were subjected to the fire and water tests, these walls were built of sections of all of the kinds and designs of tile included in the fire-endurance tests. The condition of the exposed side of three of the walls after the fire exposure and also after the subsequent water application is shown in Figures 53, 54, and 55 (pp. 152 to 154). The condition of the fourth wall after the fire exposure was similar to that shown in Figure 55.

The hose stream washed away the gypsum plaster and much of the cement plaster. (The wall for which cement plaster was used is shown in fig. 55.) It also washed out some mortar from the joints, more especially from the vertical joints, and flakes and parts of

[29] The "cement gun" is a machine with which a stream of dry cement-sand mixtures may be forced by high air pressure through a hose at the end of which it is mixed with water in a special nozzle which is manually operated at distances of from 3 to 8 feet from the surface to be coated.

shells that probably had been loosened by the fire exposures. No other effects due to the water were noted. A detailed examination to determine the condition of the individual units after the fire exposure could not be made, as the sections of different kinds of tile of which the walls were built were tested in compression. A general examination, however, showed that the condition of the individual units was such as might be expected from moderate fire exposures. Although no loads were applied to these walls during the fire and water tests, the compressive strength of the sections, as given in Table 11, indicates that large walls of all of the kinds of tile that satisfactorily carried the load during the fire-endurance tests would have carried the usual working load during the fire and water tests.

(f) TEMPERATURE TRANSMISSION

The temperature rise on the unexposed side of walls under fire exposure is governed by the intensity and duration of the exposure and is influenced by the wall thickness, the number of cells or shells through the wall thickness, the thickness of the shells, and the fire-retardant effect of the plaster, if used. In addition, the type of construction, the workmanship, and the moisture content of the wall at the time of test are important factors.

The following discussion will be based on the time required for an average temperature rise on the unexposed surface of 139° C. (250° F.) or a maximum rise at any thermocouple location of 180.6° C. (325° F.).[30]

The temperatures on the unexposed side were measured in the earlier tests with unprotected couples fastened to the wall surface. For the later tests these couples were protected with 6-inch square, dry asbestos felt pads of 0.4 inch thickness. As there is an appreciable difference in the time required to reach a definite temperature as measured with the unprotected and the protected couples, measurements by both methods were made in comparable locations in about 50 tests. It was found that the ratio of time required to obtain a temperature rise of 139° C. (250° F.), as measured by the protected couple as compared with that for the unprotected couple, varied from 0.75 to 0.90 and averaged 0.84. No consistent variation of this ratio, either with duration of test or with room temperature, was found. The average 0.84 was, accordingly, used in obtaining the calculated time required for the average temperature rise of 139° C. (250° F.) under the pads given for some tests in Table 17. To avoid confusion, the periods referred to in the discussion and conclusions will always be those pertaining to measurements made under such asbestos pads, either as actually measured in the tests or as computed from measurements made on the free surface.

[30] Appendix C (p. 330).

Some of the factors affecting temperature transmission through hollow-tile walls will be briefly discussed.

(1) Shell Thickness and Clay.—The effect of the shell thickness is shown by the curves for the walls 73 and 83 (figs. 101 and 108). The former wall was made of dense-burning fire-clay tile weighing 34.7 pounds per unit, through which the temperature rise of 139° C. (250° F.) was obtained in 1 hour 27 minutes. The latter was made of dense-burning fire clay weighing 32.3 pounds per unit, through which the same temperature rise was obtained in 1 hour 16 minutes. Generally, however, units made from the shales and dense-burning fire clays have $\frac{5}{8}$ to $\frac{3}{4}$ inch shells and those made from the surface clays and open-burning fire clays, $\frac{3}{4}$ to 1 inch shells. That walls of the denser material give a definite temperature rise in a shorter time than walls of more porous material is shown by comparing the test of wall No. 6 with that of No. 42. These were built of shale and surface-clay tile, respectively, and of approximately the same shell thickness; 1 hour 27 minutes was required to obtain a temperature rise of 139° C. (250° F.) on the unexposed surface of the shale tile wall and 1 hour 58 minutes for the surface-clay tile wall.

(2) Workmanship.—No tests were made for the purpose of bringing out the effect of workmanship on the rate of heat transmission or temperature rise on the unexposed surface of the wall. However, the time required to obtain a temperature rise of 139° C. (250° F.) on the unexposed surface of two identical end-construction walls was so decided that the difference due to workmanship became apparent. With one, No. 74, for which the webs were not bedded, 1 hour 31 minutes was required to obtain the given temperature rise, while 21 minutes longer was required for wall No. 76, in which nearly all of the webs were bedded.

(3) Design.—The difference in transmission between tiles with cells horizontal and the same tiles with cells vertical is not large for 2-cell 8-inch walls, as is shown by the wall temperatures obtained from tests 74 and 75 (fig. 102) and 79 and 81 (figs. 105 and 106). The first two walls were built of 6-cell, 8 by 12 by 12 inch fire-clay tile set on end. The others were built of the same kind of tile laid on side. For 3-cell tile, however, the difference is greater and in favor of end-construction tile. This is probably caused by better sealing of the cells by the horizontal joints with end-construction tile as compared with what obtains with the generally more imperfect vertical mortar joints between side-construction tile.

The number of cells and shells through the wall thickness has a considerable effect on the temperature rise through the wall. This is shown in the results obtained with walls 95 and 97 (figs. 118 and 120) and also 96 and 98 (figs. 119 and 121), all of which were built of 8 by 5 by 12 inch fire-clay tile weighing 14.4 pounds per unit.

The first wall of each group was built of 3-cell tile and the second of 2-cell tile. For the first group, which were 8-inch unplastered walls, 1 hour 54 minutes was required to obtain an average temperature rise of 139° C. (250° F.) on the unexposed side of the wall built of 3-cell tile and 1 hour 32 minutes for the wall built of 2-cell tile. For the last group, which were 8-inch walls plastered on both sides with gypsum plaster, the periods were 3 hours 20 minutes and 2 hours 40 minutes for the 3-cell and 2-cell tile, respectively.

The effect of increasing the number of units in a given wall thickness is similar to that of increasing the number of cells in a unit of given thickness. A case in point is that of walls 130 and 133 (figs. 150 and 153). No. 130 was built of 8 by 12 by 12 inch end-construction tile turned to expose the 8 by 12 inch face, while the other wall was built of similar 8-inch and 3¾-inch tile set side by side (see sketch on time-temperature charts). For the former, 2 hours 45 minutes was required for an average temperature rise of 139° C. (250° F.) on the unexposed side, while for the 2-unit wall 4 hours 3 minutes was required.

The reason for the slower temperature rise in walls with the greater number of cells can be attributed to the fact that for every added cell an additional longitudinal web is also added, which increases the insulation at high temperatures and presents an additional barrier to the flow of hot gases toward the unexposed side at imperfect mortar joints. Also, near the unexposed side, particularly with the heavier walls, the air spaces serve well as thermal insulators at the low temperatures prevailing during the greater portion of the test.

(4) Effect of Plaster.—Plaster retards the temperature travel through the wall and also lessens effects from workmanship, such as from imperfectly filled mortar joints. The tests indicate a slight difference in the protection afforded by gypsum and cement plaster, the difference being in favor of the former. A comparison of the time required to obtain an average temperature rise of 139° C. (250° F.) on the unexposed surface of comparable walls shows that gypsum or cement plaster on the fire side of 8-inch walls increases the time by amounts from 29 minutes to 1 hour 44 minutes and plaster on both sides of 8, 12, and 16 inch walls increases the time from 1 hour 8 minutes to 4 hours 35 minutes, the greater increases being for the heavier walls. While lime plaster generally falls off the exposed side during the first part of the test, that on the unexposed side remains in place and has an appreciable retarding effect on the temperature rise on the unexposed surface.

(5) Seasoning Conditions.—The moisture content of the walls at the time of conducting the fire test affects the temperature rise on the unexposed surface for walls of given thickness as much or more than any other one factor except plaster. As the walls of this series were

aged from one to two months, generally, at temperatures above those of the outside air, the moisture content at the time of testing was undoubtedly smaller than in exterior walls and possibly no greater than in interior walls in unheated buildings. It was, however, unquestionably not as low as that attained in fire or party walls after years of service in heated buildings. To determine the effect of this factor four walls, (Nos. 73a, 125a, 133a, and 160a) comparable with others (Nos. 73, 125, 133, and 160) which had been aged in the usual manner, were dried to nearly constant weight at temperatures near 50° C. (122° F.) before being tested. The difference in time required to obtain a temperature rise of 139° C. (250° F.) on the unexposed surface of the 8-inch unplastered walls was, however, quite minor. For the 12-inch, 2-unit, 3-cell wall the difference in period was 27 minutes and for the 12-inch, 2-unit, 4-cell (T-shaped tile) wall it was 2 hours 52 minutes. For the 16-inch wall (H-shaped tile) the difference was 1 hour 47 minutes. As most of the water content of the walls is contained in the mortar joints, it can readily be understood why the difference for the third wall mentioned above was greater than for the other walls, since the units for this wall are small and the design of the units is such that somewhat more mortar is required than with other designs included in the comparison.

These walls were dried to a condition where they would gain slightly in weight at ordinary temperatures and were thus in a little drier condition than attainable for interior walls. However, the differences in resistance periods obtained must be considered in applying the results of fire tests of normally seasoned walls to fire conditions in buildings.

(6) Temperature Rise at Single Locations.—While the fire-resistance periods of the walls were generally determined by the 139° C. (250° F.) average temperature rise as obtained from the average of the readings of all thermocouples placed in the required locations at different points on the unexposed surface, the period for 19 walls (Table 17) was determined by the 180.6° C. (325° F.) temperature rise at any one thermocouple location. All but four of the walls whose period was thus determined were of 8-inch thickness.

(7) Temperature Rise After Fire Test.—The maximum temperature rises after the fire was shut off, taken as the average for the locations in which readings were taken, are given in Table 17 and on the time-temperature plots, both as measured on the free surface and under the asbestos pads. Considering only the tests for which the fire was shut off within 10 minutes of the time when the 139° C. (250° F.) temperature rise obtained under the small pads, the total rise at the same points ranged from 182 to 260° C. (328 to 408° F.) in the different tests. Such temperature rises are incident with fire tests or fire exposures of walls and partitions, generally. No limits

for the permissible temperature rise under these conditions are prescribed in the standard fire-testing procedure, and such limits can be applied with difficulty, since it presupposes the possibility of estimating in advance what the rise will be and stopping the test in time to prevent it from being exceeded. Examination of the results of some tests (Table 17, Nos. 117, 118, 127, 128, 153, 157, and 162) indicates that where the test is stopped at 80 to 90 per cent of the time when the 139° C. (250° F.) temperature rise would obtain under the pads, the average temperature rise under the pads on the unexposed surface after the fire is shut off will be within 180° C. (324° F.). This would give fair assurance against ignition of combustible materials against the unexposed side of the wall, considering that after the peak of the fire is past there is less pressure from gases of combustion and the temperature difference between points on the unexposed side becomes smaller. Temperature measurements under the large cotton pad and excelsior box placed against the unexposed side of a number of the walls tested indicated border temperatures of 250° C. (482° F.) to obtain before ignition takes place. Considering that the results of fire tests must be applied to fire conditions in buildings with a factor of safety considerably in excess of the 10 to 20 per cent difference in time between the fire-resistance period as regularly determined and the time limit on the fire exposure set by the subsequent temperature rise, the latter can be considered as provided for in the margin with which the test results must be applied.

(8) Temperatures Under Large Pads and at Cracks.—Taken as the average from 27 tests in which good comparisons were obtained, the cotton or excelsior pads were removed from the wall after ignition 19 minutes after a temperature of 250° C. (482° F.) was registered under the pad. Without doubt, portions of many of the pads ignited before the smoke gave evidence of ignition, this being particularly true of the cotton pads. On the other hand, higher temperatures than those indicated at the single-couple location under each pad undoubtedly obtained under it at other points. Taking a temperature rise of 200° C. as the highest permissible under the large pads and at cracks, this was attained earlier than the fire-resistance period, as determined by the 139° C. (250° F.) temperature rise under the asbestos pads, in four tests under the cotton pads (Nos. 87, 105, 106, and 128), and in two tests at cracks (Nos. 37 and 69). The temperatures under the excelsior box did not reach points in any test that would require consideration on this basis. No ignition for either cotton or excelsior occurred at a time where it would modify the fire-resistance period as otherwise determined. After the fire was shut off with surface temperatures within safe limits, temperatures at cracks, generally, soon began to go down, while under the cotton pads they continued rising, often resulting

in ignition several hours later. Hence, while the temperatures recorded at cracks and under the large pads may not indicate any change in the fire-resistance classification, as otherwise determined, they do show that the periods determined according to the regular procedure often represent the ultimate, or near ultimate, fire resistance of the construction, and that a proper factor of safety must be used in applying them to fire conditions in buildings.

9) FLAME PASSAGE.—In one test (No. 4) the fire-resistance period was determined by flame passage from spalling through of an 8-inch unplastered wall. In two other tests of 8-inch plastered walls (Nos. 8 and 15) holes from spalling were formed through the walls 21 minutes and 2 hours 15 minutes after the respective fire-resistance periods of the walls had been reached. In a fourth similar test (No. 9) the tile spalled through to the plaster on the unexposed side, which stayed in place during the test. The tile in all of these walls were from one shipment of shale tile from source *d* that contained a number of vitrified tile easily distinguished by the darker color. While tile from this source range normally in absorption from 5 to 10 per cent (Table 14), vitrified tile similar to those that spalled through had absorption of less than 2 per cent. In constructing further walls from this lot of tile the vitrified units were not used, and no further trouble from this cause was encountered. The vitrified tile are not well adapted for setting in the wall, as they are shorter than the normally burned units and mortar and plaster adhere to them with difficulty. Their acceptance for locations other than foundations and other uses where they will not be exposed to fire should be precluded by proper provisions in specification and building-code requirements.

To determine more definitely the relation between hardness of burning and susceptibility to spalling of shale tile, a fire test of an 8-inch unplastered wall built of 8 by 12 by 12 inch and 8 by 12 by 6 inch end-construction (design A) tile from source *d* was conducted in the small furnace. The tile were selected to give a wide range in hardness, the absorption varying from 1.4 to 10.3 per cent, the value for each tile being taken as the average from determinations made by the one-hour boiling method on three pieces from different parts of the unit.

The test was continued for 1 hour 32 minutes. The inner shells of three units having absorption below 4 per cent were spalled through before the end of 16 minutes, and a hole was formed for the whole thickness of one tile having absorption of 1.4 per cent at 44 minutes. No other holes permitting flame passage were formed during the test, although at the end of the test a tile having absorption of 2.1 per cent had spalled through to the exposed shell and the center longitudinal web, and the unexposed shell was spalled to a depth of ⅛ to ¼ inch

over a portion of its area. The furnace glow could be seen through a crack in the shell.

In the examination of the tile after test it was further found that tile with absorptions from 2 to 6 per cent had spalled on the exposed surface to various depths, but only for two, having absorptions of 2.1 and 3.9 per cent, had holes been formed in the exposed shell. The effects were noticeably less marked for tile having absorption above 4 per cent than for those with lower absorption. The units with absorption of over 6 per cent showed no spalling effects, although, generally, the webs holding the exposed shells were cracked.

This test, therefore, indicates that shale tile with absorption of less than 4 per cent is likely to show decided spalling effects when exposed to fire, and that with absorptions as low as 2 per cent holes may be formed through 8-inch unplastered walls before the fire-resistance period, as based on temperature rise, is normally reached. It might be noted that the average absorption of sample lots of four or five units from shipments that contained tile showing decided fire effects in the regular tests ranged from 5.3 to 6.7 per cent, with individual minimums of 1.2 to 5.6 per cent (Table 14).

Another way in which openings allowing passage of flame were formed or enlarged was by allowing the flame to act on the whole thickness of the tile at the ends of the wall, as well as on the exposed surface. In test Nos. 2 and 3 of hard-burned shale tile, portions of the walls at the top corners were dislodged by cracking and falling of the tile after one-half hour of fire exposure, although the walls carried working load of 120 lbs./in.^{2} for 2 hours 51 minutes, or about one hour longer than their fire-resistance period as determined by temperature transmission at other points on the unexposed side. Wall No. 4 was of the same kind of tile and otherwise identical with Nos. 2 and 3, except that the openings between the wall and the frame and between the two halves of the wall were fire stopped so that only the inner surface of the wall was exposed to fire. Tested under load of 80 lbs./in.^{2} increased at the end of the test to 120 lbs./in.^{2}, no spalling at the ends of the wall occurred. The conditions under which walls Nos. 2 and 3 were tested approximate those for exterior walls with openings, rather than those for party and fire walls and, hence, the results can not be taken as applying for walls used for fire-division purposes. They must, however, be considered in connection with exterior walls having openings. It might be noted that the effects obtained with walls 3 and 4 were with 8-inch unplastered and unstuccoed walls of tile particularly susceptible to fire damage. With tile less subject to fire effects, or where plaster or stucco is present, less fire damage at the wall openings is to be expected.

14. FIRE-RESISTANCE PERIODS OF HOLLOW-TILE WALLS

The term "fire-resistance period" as applied to load-bearing walls and partitions refers, according to present usage, to the ultimate time resistance of the construction as subjected to the standard fire test, determined by the one of the following end points that gives the shortest duration: (1) Failure under the applied working load, (2) passage through the wall or partition of flame or gases hot enough to ignite ordinary combustible materials, and (3) an average temperature rise on the unexposed surface of 139° C. (250° F.) or a rise of 180.6° C. (325° F.) at any point at which temperatures are measured. Ability to meet the requirements of the fire and water test is also required. For nonbearing walls and partitions the same requirements hold with the exception of (1).

(a) METHOD OF DERIVATION

The fire-resistance period for the walls tested was generally determined by the time required to attain an average temperature rise of 139° C. (250° F.) on the unexposed surface as measured under asbestos pads. In some cases the maximum permissible temperature rise at any one thermocouple location governed, and in one case the period was determined by flame passage. In eight tests it was limited by load-carrying ability.

On side-construction tile 80 lbs./in. was generally applied and 120 lbs./in.^{2} on end-construction tile. Information on strength of hollow-tile masonry,[31] obtained after this work was begun, indicated a smaller difference between the strength of side and of end construction walls than these loads would indicate. For the compression tests of masonry specimens, conducted in connection with the fire tests, the average strength for side construction was 383 lbs./in.^{2} and for end construction 472 lbs./in.^{2} The average strengths of specimens cut from the walls after fire test was 218 and 287 lbs./in.^{2} for side and end construction, respectively. Hence, there is also indicated for the load-carrying ability of the respective constructions under fire conditions a smaller proportionate difference than might be inferred from the loads applied.

The fire and water tests of walls built of sections containing tile of nearly all designs and from sources typical of those included in the fire-endurance tests indicated adequacy when in a highly heated condition to meet the requirements relative to resistance to hose streams.

From the standpoint of temperature transmission, the results from the large and the small furnace are considered of equal import. Examination of results with comparable constructions tested in both furnaces indicates a little lower periods for tests in the small furnace. This may be due to somewhat drier seasoning conditions for the smaller walls and a little higher furnace temperature during the test (see fig. 18).

[31] B. S. Tech. Paper No. 311.

The tests of many of the walls were stopped, for reasons previously stated, before the limiting temperatures were obtained on the unexposed surface, and their results, while not directly usable for determining fire-resistance periods, give important information on fire effects for exposures of shorter duration than the full fire-resistance period.

(b) TABLE OF FIRE-RESISTANCE PERIODS

The periods given in Table 19 are based mainly on temperature transmission. They are arranged according to two main subdivisions in point of clay material, then further, according to the number of units and cells in the wall thickness and the design of the unit. To reduce the size of the table, results of tests of restrained and unrestrained walls are grouped with those made under load. The tests give no evidence that walls functioning satisfactorily as load-carrying members would not also serve as restrained or unrestrained walls, the differences noted between results with the respective test conditions being mainly in the residual fire effects on the tile units. Where only the tests with the restrained or the unrestrained walls were made, the load-carrying ability can be judged by performance of similar tile in thinner walls or walls without plaster protection.

The load-carrying ability of constructions tested under load only in the small furnace can be judged also by the time the load was carried beyond the nominal resistance of the wall and the excess load carried at the end of the fire test. The program was planned so that all tile subject to failure under load would be represented in tests in the large furnace. This could not be done in all cases, especially for the heavier walls, and some doubt remains as to the validity of periods extending beyond six or eight hours, particularly for tile showing decided fire effects. However, resistances of over eight hours would be required for only exceptional conditions, and, from the standpoint of practical application of the results, an uncertainty of an hour or two as to what the period should be would be of less significance than for shorter periods. For the shorter periods, ability of walls without window, door, or other openings to sustain loads of 80 lbs./in.^{2} for fire-exposure periods up to or beyond the time when limiting temperatures obtain on the unexposed side was shown to hold for nearly all of the tile materials, designs, and constructions tested. Failure under 120 lbs./in.^{2} load occurred in some tests of 8-inch unplastered walls built of tile particularly subject to fire damage. Increased load-carrying ability, as well as temperature insulation, was shown to obtain if the tile were covered with plaster or stucco. A further margin of safety is obtainable by increasing the wall thickness beyond the 8-inch minimum.

For walls pierced by door or window openings, the tests do not give definite information on the score of load-carrying ability, as no walls directly representative of this condition were tested. Indications from one test, where the ends of the wall were exposed to fire, were that the fire effects are more severe than for unpierced walls

where only the one side is so exposed. Hence, the general desirability of building bearing walls for such purposes in greater thickness than 8 inches, or protected by plaster, furring and plaster, brick, or stucco. This is particularly important where tile subject to severe fire damage is used and where interior fire-resistive floor construction is dependent for stability during the fire and safety and possibility of reuse after the fire on the condition of the wall construction.

In Figure 20 is shown, by the length of the lines, the fire-resistance periods developed in the fire-endurance tests. These are determined by temperature transmission or load failure. The solid lines indicate periods determined by the 139° C. (250° F.) temperature rise measured under the asbestos pads. The crosshatched lines indicate periods calculated for the same basis from temperature measurements made on the free unexposed surface of the wall as previously explained (p. 98).

(c) SUMMARY OF FIRE-RESISTANCE PERIODS

The results of the tests are further summarized in Table 20, where those with the different tile designs are placed in three classes as determined by the resistance periods developed. The classes are derived directly from those in Table 19 by combining the results from all types of clay. This was considered necessary, since the clay used by many plants does not definitely come within either of the two general types with reference to which the results in Table 19 are grouped, or are mixtures of different kinds of clay. Also, for some classes of designs and wall thicknesses, tests were made with only one kind of clay, and it appears better to derive from the results a general value rather than to attempt to obtain from the results with one type of clay the values that would hold for another. The physical properties of tile from the two general clay groups of Table 19 also overlap. Thus, some lots of dense-burning fire-clay tile have a higher absorption than some tile from surface clay, and a similar overlap exists in point of compressive strength and modulus of elasticity. (Compare tests from sources *l* and *k*, Table 14.) The resulting range in results for a given class of tile design and wall thickness will be somewhat greater than for the groupings in Table 19, but if the fire-resistance periods are applied with the proper factor of safety, a margin large enough to comprise these varations will be provided. Thus, if a wall construction is used that, according to Table 20, has an ultimate fire resistance about 50 per cent in excess of the estimated equivalent duration of the fire that can arise in the building or portion thereof where the wall is located, a margin will be present that in most cases will be greater than the variation in results of the individual tests on which the given value in Table 20 is based. This larger margin is desirable in that some allowance is needed for variations in material and workmanship beyond what was developed in the tests and also to compensate for errors in estimating the severity of the fire condition for which the structural protection is provided.

TABLE 19.—*Ultimate fire-resist*

Wall thickness (in inches)	Number of units in wall thickness	Number of cells in wall thickness	Letter, Figure 13	Design of unit: Shape	Design of unit: Nominal size (inches)	Design of unit: Average weight	Kind of clay	Average absorption
						Pounds		*Per cent*
8	1	2	A, B	6-cell end construction.	8 by 12 by 12	35.5	Shale or dense-burning fire clay.	9.0
			A	do	do		do	12.3
			L	2-cell back up	8 by 5 by 12	15.7	do	9.9
8	1	2	A, B	6-cell end construction.	8 by 12 by 12	35.3	Surface clay or open-burning fire clay.	14.9
			L	2-cell back up	8 by 5 by 12	14.6	do	14.7
8	1	2	A, B	6-cell end construction.	8 by 12 by 12	32.9	Shale or dense-burning fire clay.	10.0
			A	do	do		do	6.4
			L	2-cell back up	8 by 5 by 12	14.4	do	
8	1	2	B	6-cell end construction.	8 by 12 by 12	35.8	Surface clay or open-burning fire clay.	11.5
8	1	2	A, B	do	do		Shale or dense-burning fire clay.	8.0
			A	do	do		do	13.2
8	1	2	A, B	do	do	36.0	Surface clay or open-burning fire clay.	14.2
		3	K	3-cell back up	8 by 5 by 12	15.2	Shale or dense-burning fire clay.	10.5
		3	Q	Cube	8 by 8 by 8	17.3	do	9.2
		3	P	H-shaped	8 by 10¼ by 12	32.7	do	11.9
8	1	3	R	do	8 by 8 by 12	25.6	do	11.5
		1+	E [2]	Double shell	8 by 12 by 5	17.2	do	8.8
		2+	D	do	8 by 12 by 12	39.1	do	6.9
		2+	S	do	8 by 5 by 12	18.2	do	3.1
8	1	3	K	3-cell back up	do	16.6	Surface clay or open-burning fire clay.	18.9
			U	6-cell side construction.	8 by 6 by 12	19.9	do	20.3
		3	O	T-shaped	8 by 6¼ by 12	16.3	Shale or dense-burning fire clay.	10.2
8	1	3+	T	Double shell	8 by 3½ by 12	15.4	do	3.4
		3+	T	do	do	15.4	do	3.4
8	1	3	C	9-cell end construction.	8 by 12 by 12	35.0	Surface clay or open-burning fire clay.	22.2
			O	T-shaped	8 by 6¼ by 12	15.2	do	11.5
		3	Q	Cube	8 by 8 by 8	17.2	Shale or dense-burning fire clay.	9.4
8	1	3	R	H-shaped	8 by 8 by 12	25.6	do	11.5
		2+	S	Double shell	8 by 5 by 12	18.2	do	3.1
8	1	3	C	9-cell end construction.	8 by 12 by 12	35.0	Surface clay	22.2
		3	K	3-cell back up	8 by 5 by 12	14.4	Shale or dense-burning fire clay.	
8	1	3	Q	Cube	8 by 8 by 8	17.3	do	8.2
		3	Q	do	do	17.5	do	9.0
		3	P	H-shaped	8 by 10¼ by 12	34.8	do	12.6
		1+	E [2]	Double shell	8 by 12 by 5	16.0	do	5.3
		2+	D	do	8 by 12 by 12	39.1	do	6.9

[1] These periods apply only where the hollow space between the ends of the combustible members and the opposite face of the wall is unfilled.

ance periods of hollow-tile walls

How tested	Plaster		Wall Nos.	Building members projecting into wall					
				None or incombustible			Combustible [1]		
	Exposed side	Unexposed side		Range		Average	Range		Average
				H. m.	*H. m.*	*H. m.*	*H. m.*	*H. m.*	*H. m.*
On end	None	None	1, 2, 3, 6, 7, 11, 73, 73a, 74, 75, 76, 83	1 11	to 1 52	1 31	0 50	to 1 16	1 03
On side	do	do	79, 81	1 20	to 1 30		0 58	to 1 05	
do	do	do	18, 97	1 31	to 1 49		1 10		
On end	do	do	41, 42, 43, 44, 67, 69, 71	1 18	to 2 23	1 56	0 56	to 1 53	1 19
On side	do	do	62, 63	1 48	to 1 49		1 10	to 1 15	
On end	Gypsum or cement.	do	77, 78, 85	1 44	to 2 41	2 27	1 24	to 2 00	1 52
On side	Gypsum	do	8	2 45			2 25		
do	Gypsum (fell off).	Gypsum	98	2 23			1 40		
On end	Gypsum	None	45	----------		3 19	----------		2 05
do	do	Gypsum	9, 84, 86, 87	3 12	to 4 06	3 37	1 32	to 2 25	1 56
On side	do	do	80, 82	3 17			1 38	to 2 05	
On end	Gypsum or cement.	Gypsum or cement.	46, 68, 70, 72	3 45	to 4 37	4 21	1 54	to 2 30	2 17
On side	None	None	17, 95	1 54			0 44		
do	do	do	24, 107	1 49	to 2 25		0 49	to 1 10	
do	do	do	22, 23, 103, 104, 105	1 45	to 2 26	1 57	0 43	to 1 02	0 53
do	do	do	26	1 13			0 32		
On end	do	do	91, 92, 93	1 52	to 1 59		0 42	to 0 49	
do	do	do	89	1 59			1 06		
On side	do	do	30	2 04			1 33		
do	do	do	61, 94, 99	2 08	to 2 49	2 29	0 51	to 0 57	1 00
do	do	do	64	2 49			1 18		
do	do	do	19, 20, 21, 101, 102	2 09	to 2 57	2 30	0 54	to 1 28	1 22
do	do	do	28	2 23			1 52		
do	Gypsum (fell off).	do	29	2 31			2 08		
On end	None	do	38	3 27		2 51	1 32		1 17
On side	do	do	60, 65	2 02	to 3 03		0 58	to 1 22	
do	Gypsum	do	25	3 06		2 50	2 11		1 50
do	do	do	27	2 49			1 15		
do	do	do	31	2 35			2 05		
On end	do	do	36, 39	----------		4 42	----------		2 38
On side	do	Gypsum	96	3 20			----------		
On end	do	do	109	3 35			----------		
On side	do	do	108	3 33		3 37	----------		1 56
do	do	do	106	4 52			----------		
On end	do	do	15	2 09			1 47		
do	do	do	90	4 14			2 04		

[1] Without a center longitudinal web, as in Figure 11–A.

TABLE 19.—*Ultimate fire-resistance*

Wall thickness (in inches)	Number of units in wall thickness	Number of cells in wall thickness	Letter, Figure 13	Design of unit: Shape	Design of unit: Nominal size (inches)	Design of unit: Average weight	Kind of clay	Average absorption
						Pounds		*Per cent*
8	1	3	C	9-cell end construction.	8 by 12 by 12	35.0	Surface clay	22.2
8	?	1	J	Brick backer	3¾ by 12 by 10½	16.9	Shale or dense-burning fire clay.	8.4
			M	1-cell back up	3¾ by 5 by 12	9.0	do	8.1
8	1+	2+	B	6-cell end construction.	8 by 12 by 12	30.6	do	8.5
			I	Furring	2 by 12 by 12			
8	1+	2+	A	6-cell end construction.	8 by 12 by 12		do	6.7
			I	Furring	2 by 12 by 12			
10	2+	2+ 2-inch air space.	H	3-cell end construction.	3¾ by 12 by 12	17.2	do	10.2
			N	2-cell back-up	3¾ by 5 by 12	8.6	do	10.7
12	1	3	A	6-cell end construction.	8 by 12 by 12	35.1	do	10.6
12	1	3	G	9-cell end construction.	12 by 12 by 12	51.2	Open-burning fire clay.	16.8
12	1	3	G	do	do	51.2	do	16.8
12	2	3	A	6-cell end construction.	8 by 12 by 12	35.1	Shale or dense-burning fire clay.	10.2
			H	3-cell end construction.	3¾ by 12 by 12	19.0	do	8.2
12	2	3	B	6-cell end construction.	8 by 12 by 12	35.8	Surface clay or open-burning fire clay.	11.5
			J	3-cell end construction.	3¾ by 12 by 12	21.9	do	15.8
12	2	4	P	H-shaped	8 by 10¼ by 12	34.8	Dense-burning fire clay.	12.6
			Q	Cube	8 by 8 by 8	17.8	do	9.0
12	2	4	O	T-shaped	8 by 6¼ by 12	16.0	Shale	12.8
12	2	4	C	9-cell end construction.	8 by 12 by 12	35.0	Surface clay	22.2
			H	3-cell end construction.	3¾ by 12 by 12	18.1	do	18.0
			O	T-shaped	8 by 6¼ by 12	15.8	do	14.4
12	2	4	P	H-shaped	8 by 10¼ by 12	34.8	Dense-burning fire clay.	12.6
			Q	Cube	8 by 8 by 8	17.8	do	9.0
12	2	4	O	T-shaped	8 by 6¼ by 12	15.8	Surface clay	14.4
12	2	2	V	6-cell end construction.	8 by 12 by 10½	28.0	Dense-burning fire clay.	6.5
			X	L-shaped	8 by 5 by 12	15.3	do	6.5
			Z	Brick	2¼ by 3¾ by 8			13.6
			L	2-cell back up	8 by 5 by 12	14.4	Dense-burning fire clay.	
			M	1-cell back up	3¾ by 5 by 12	9.0	do	8.1
			Z	Brick	2¼ by 3¾ by 8			13.6
16	2 or 3	4	A	6-cell end construction.	8 by 12 by 12	35.3	Shale or dense-burning fire clay.	9.1
			H	3-cell end construction.	3¾ by 12 by 12	18.2	do	10.3
			L	2-cell back up	8 by 5 by 12	14.4	do	
			M	1-cell back up	3¾ by 5 by 12	9.0	do	8.1

periods of hollow-tile walls—Continued

How tested	Plaster		Wall Nos.	Building members projecting into wall			
				None or incombustible		Combustible	
	Exposed side	Unexposed side		Range	Average	Range	Average
				H. m. *H. m.*	*H. m.*	*H. m.* *H. m.*	*H. m.*
On end	Cement	Cement	37		6 00		
do	Gypsum	Brick	113	4 33	4 44	2 01	2 14
On side	do	do	112	4 56		2 26	
On end	Gypsum on furring tile.	None	88		3 42		
do	Gypsum on furring tile.	Gypsum	13, 14	5 26 to 6 05	5 46	3 32 to 3 40	3 36
On side	Gypsum	Cement	110	4 07	4 06	1 12	1 16
do	do	do	111	4 06		1 20	
On end	None	None	114, 115, 130, 131, 132	2 45 to 3 02	2 56	2 24 to 2 45	2 38
do	do	do	135		3 17		3 00
do	Gypsum	Gypsum	136		6 00+		5 00
do	None	None	116, 133, 133a	3 36 to 4 03	3 50	3 02 to 4 36	3 46
do	do	do	124		5 01		2 21
On side	do	do	137	5 05	4 48	2 46	2 43
do	do	do	139	4 32		2 40	
do	do	do	118				4 25
do	do	do	120	5 22	6 31	4 05	4 41
			125, 125a, 127	5 40 to 8 32		3 40 to 5 54	
do	Gypsum	Gypsum	138	8 37	7 38	5 25	4 32
do	do	do	140	6 39		3 40	
do	do	do	126		10 43		6 30
On end	Gypsum (fell off).	Brick	147	6 00+	6 00+	3 08	3 20
On side							
do							
do	do	do	146	6 00+		3 32	
do							
On end	None	None	148, 151, 152, 153	4 11 to 6 50+	5 50+	4 38 to 6 10	5 32+
On side	do	do	155	6 00+		6 00+	

TABLE 19.—*Ultimate fire-resistance*

Wall thickness (in inches)	Number of units in wall thickness	Number of cells in wall thickness	Letter, Figure 13	Design of unit: Shape	Design of unit: Nominal size (inches)	Design of unit: Average weight	Kind of clay	Average absorption
						Pounds		*Per cent*
16	2 or 3	4	A	6-cell end construction.	8 by 12 by 12	35.2	Shale or dense-burning fire clay.	11.5
			H	3-cell end construction.	3¾ by 12 by 12	17.0	do	9.4
16	2 or 3	5 or 6	K	3-cell back up	8 by 5 by 12	14.4	Dense-burning fire clay.	
			M	1-cell back up	3¾ by 5 by 12	9.0	do	8.1
			Q	Cube	8 by 8 by 8	17.5	do	9.0
			P	H-shaped	8 by 10¼ by 12	34.8	do	12.6
16	2 or 3	6	O	T-shaped	8 by 6¼ by 12	15.8	Surface clay	14.4
16	2 or 3	5 or 6	K	3-cell back up	8 by 5 by 12	14.4	Dense-burning fire clay.	
			M	1-cell back up	3¾ by 5 by 12	9.0	do	8.1
			Q	Cube	8 by 8 by 8	17.5	do	9.0
			P	H-shaped	8 by 10¼ by 12	34.8	do	12.6
16	2 or 3	6	O	T-shaped	8 by 6¼ by 12	15.8	Surface clay	14.4

periods of hollow-tile walls—Continued

How tested	Plaster		Wall Nos.	Building members projecting into wall			
				None or incombustible		Combustible	
	Exposed side	Unexposed side		Range	Average	Range	Average
				H. m. H. m.	*H. m.*	*H. m. H. m.*	*H. m.*
On end	Gypsum	Gypsum	154		9 24+		9 12
On side	None	None	157	8 45+	8 54+		6 52
do	do	do	162	7 01+		6 20	
do	do	do	160, 160a	9 00 to 10 52		6 10 to 8 06	
do	do	do	149		13 52		12 22
do	Gypsum	Gypsum	158	12 52	12 24		7 58
do	do	do	163	10 45		7 18	
do	do	do	161	13 35		8 39	
do	do	do	150		18 15		13 58

TABLE 20.—*Summary of ultimate fire-resistance periods*

Design of unit [1]			Nominal wall thickness	Number of units in wall thickness	Number of cells in wall thickness	Sides covered with plaster or stucco	Building members projecting into wall	
Class	Letter in Figure 13	Description					None, or incombustible	Combustible [1]
			Inches				*Hours*	*Hours*
II	C, O, T	3-cell end construction, T-shaped, or double-shell plus 3 interior cells.	8	1	3	None	2¾	1¼
						One	3¾	1¾
						Both	5	2¾
			12	2	4	None	6	4
						Both	9	6½
			16	2 or 3	5 or 6	None	11	8
						Both	15	10
III	K, P, Q, D, E, S	3-cell side construction, or double-shell plus one or two interior cells.	8	1	3	None	2¼	1
						One	3	1
						Both	4	2
			12	2	4	None	5	3
						Both	7½	4½
			16	2 or 3	5 or 6	None	8½	6¼
						Both	12	8
IV	A, B, G, L	2-cell end or side construction.	8	1	2	None	1¾	1
						One	2¾	1
						Both	4	2
			12	1	3	None	3	2¼
						Both	6	4
			12	2	3	None	4	3¼
						Both	6½	4½
			16	2 or 3	4	None	6	5¼
						Both	9	7
IV. Brick-faced	J, L, M, V, X, Z	End or side construction to line up with brick.	8	2	1	One	4½	2
			12	2	2 or 3	None	6	3¾
						One	7	3¾
IV. Furred on one side.	A, B, L, I	End or side construction to line up with furring.	8	1+	2+	do	3¾	1
						Both	5½	2
IV. With air space	H, J, M	3¾-inch 1-cell end or side construction.	10	2	2+ 2-inch air space	do	4	1

[1] The designs noted are those of the major units entering into a given construction. The number of cells is the number in an 8-inch thickness taken at right angles to the wall line.

[2] These periods apply only where the hollow space in the wall near the combustible members is unfilled. Where the space is filled solidly with incombustible and fire-resistive materials for the full thickness of the wall and for 4 inches or more above, below, and between the members the periods given for incombustible members apply, except that for 8-inch walls unplastered or plastered on one side periods exceeding two hours can not be taken, and for 8-inch walls plastered on both sides the maximum period to be taken with combustible members is four hours.

The periods in Table 20 have been taken to the nearest 15 minutes for durations up to four hours and at half-hour intervals thereafter. Where the tests on which the periods are based are mainly or only with tile of the hard-burning groups, the value for Table 20 was taken in some cases a little higher than the average for the tests considered and lower where the tests were only with the open-burning clays. For the heavier wall constructions, the value in Table 20 is near the average obtained with the group giving the lowest result.

For the 8-inch walls, periods are given for plaster applied on one side. As it concerns protection for combustible members projecting into the wall, the plaster in this case is assumed to be on the same side as these members and thus affords them no protection against a fire exposing the opposite side of the wall. While this assumption can be made under most conditions, periods for the case where plaster on one side protects such members can be taken the same as those given for plaster on both sides, as it concerns the wall construction with such members projecting into it, and the same as those for plaster on one side, for walls without them.

The higher resistance periods for the first class in Table 20 can be attributed to the design of the units. The 3-cell end-construction design has two shells and two interior webs effective in retarding the heat flow, also the two transverse shells and webs are partly effective, since they are short and spaced relatively close together. The horizontal mortar joints of end construction are more likely to be well filled than the vertical joints between side-construction tile, thus giving a better seal between the cells. With the T-shaped unit, there are no full horizontal or vertical joints directly through the wall, and the horizontal webs and shells are staggered so that almost all parts of the unit are effective in retarding temperature transmission. The double-shell tile with two interior longitudinal webs contains less void space than other designs, and the good mortar joints obtainable with the double shells aid materially in increasing the fire resistance of the wall construction.

The loads that can be safely applied for the periods given in Table 20 have been previously discussed. While tile of a number of designs and clays safely carried loads in excess of 80 lbs./in.^{2} of gross bearing area, generally it appears desirable to limit the working load to this value.

The periods are based on the assumption that the tile are laid up with a Portland cement or cement-lime mortar comparable with those used in the walls tested. No fire tests were made with tile set in lime mortar. Strength tests of walls [32] indicate a decidedly lower strength with lime mortar, and, irrespective of the extent to which this would be reflected in results of fire tests, it appears desirable that hollow-tile walls be always built with the stronger mortars.

The combinations of design, clay, and manufacturing details producing tile whose fire resistance is limited by load-carrying ability or local spalling effects to periods lower than those obtained from general temperature transmission through the wall have also been discussed. Ability as exposed to fire to support loads up to 80 lbs./in.^{2} of gross bearing area was shown to obtain for nearly all of the tile tested. Spalling effects of sufficient extent to limit fire-

[32] B. S. Tech. Paper No. 311.

resistance periods determined by temperature transmission was present only with very hard burned tile units having an absorption of 2 per cent or less. Where doubt exists on these points, the purpose of safety can be served by increasing the wall thickness 4 inches above that required for the working load or the temperature rise on the unexposed side, using not less than two units in the wall thickness. Plaster or stucco is also effective in reducing fire effects to the point where ability to support working loads can be assumed. Plaster or stucco on clay furring tile will prevent all fire damage to the structural portion of the wall from severe fires. Brick facing serves a similar purpose in protecting tile backing against damage from exterior fire exposures.

V. APPLICATION OF RESULTS TO FIRE CONDITIONS IN BUILDINGS

The preceding parts of this paper deal with methods and results of tests conducted according to testing procedures, formulated after some 30 years of experience with materials of modern fire-resistive building construction in building fires and fire tests.

As an aid in determining to what extent the procedure and the test results accord with fire experience with materials and constructions in building fires, a brief summary of available information on the comparability of exposure conditions and their effects will be made.

1. INTENSITY AND DURATION OF BUILDING FIRES

On the point of the validity of the fire temperatures and durations incident with the fire tests, the extent to which the severity of building fires is known in terms of fire temperatures and durations becomes important. The fire records generally give little information on either intensity or duration as it applies to the portion of a building contributing to the fire exposure for a given building member. Estimates of temperatures have been made from fused metals, or other materials left by the fire, but the length of time the high temperatures obtained remained conjectural. There would also be uncertainty in some cases as to whether fusion was caused by contact with flames and gases of combustion or with glowing débris.

Some information has also been obtained from fire effects on materials and constructions similar to those that have been subjected to fire tests. As it concerns hollow-tile construction, fire effects comparable with the range developed in these tests have been observed after building fires. With fires of short or moderate durations and favorable tile material or protection, the damage has been very minor. With similar fire exposures, in other cases the exposed shells have spalled off. The exterior appearance of the wall is often no criterion of the effects of the fire. After the majority of the fire

tests reported in this paper, the visible effects on the wall exterior were very minor. Some of the photographs in Figures 21 to 55 will serve to indicate this. Only a few of those showing little or no fire effects were published, since, in order to keep the size of the report within the required limits, only those could be included that contained details not shown in other views.

Information on fire severity has also been developed in burning-out tests with occupancies housed in fire-resistive buildings, with measurement of air and débris temperatures from the start of the fire until the ruins cooled down. Such tests, conducted with office occupancy with desks, filing cabinets, shelves, and their contents, have been conducted at the Bureau of Standards from which information on rate of temperature rise, temperatures, and durations have been obtained. With a start for the fire, such as from a burning waste-paper basket, the fire will be confined to near the point of origin until room temperatures are built up sufficiently to cause ignition, ready combustion, and spread of fire to other portions of the room. From this point on the temperature rise is rapid and fully equal to that incident with the first part of the regular fire test. The duration of the fire and its intensity depend on the amount of combustibles present, 10 lbs./ft.^{2} of furniture and contents, assumed distributed over the floor area, giving a fire equivalent approximately to the first hour of the standard furnace test, and 20 lbs./ft.^{2} equivalent to a two-hour test, the latter being apparently near the upper limit of severity for the occupancy as such. However, concentrations of 50 to 60 lbs./ft.^{2} of books and records on combustible shelving gave equivalent fire durations of between six and eight hours, as referred to the standard furnace test.

When the fire was given a quick start in a sufficient quantity of readily combustible materials the initial lag was eliminated, and the period of rapid temperature rise was comprised within the first 20 to 60 minutes of the fire. For the longer durations the fall in temperature after the maximum was passed was slower than in test-furnace chambers after the fire is shut off, which possibly implies less damage from rapid cooling. However, in fires, cooling from the application of hose streams must be premised that would be fully as destructive as rapid air cooling.

This work has thus given information on the validity of the testing procedure as it concerns the severity of the test fire exposure, and it has also indicated possibility of applying the results of furnace tests on a quantitative basis to fire conditions in fire-resistive buildings. The combustible contents of the lighter occupancies from the fire-hazard standpoint, such as residential, institutional, and office or light commercial, consist mainly of wood furniture, paper records, and combustible top floors and trim, and the probable severity of a

fire consuming them can be gauged by the total combustible contents per unit of floor area. For occupancies involving larger amounts of combustibles the character of the materials would have a greater influence on the severity of the fire.

For buildings with combustible interior floors, floor framing, and partitions, estimates of equivalent fire durations are subject to greater uncertainty, although, until the floors or roof collapse, fire conditions will approximate those in a fire-resistive building designed to withstand a complete burning out of contents without collapse of structural members.

2. FIRE-EXPOSURE CONDITIONS FOR WALLS

Masonry walls serve an important purpose in decreasing the fire hazard both as it concerns protection for the community against spread of fire and protection for the individual building.

(a) EXTERIOR EXPOSURE

Walls should be adequate in preventing ignition of building members and contents from heat conduction induced by fire in neighboring buildings. The severity of the exposure is usually less than from interior fires, except for party and fire walls dividing attached buildings. There is a difference in resistance between walls with and without combustible floor or other members projecting into them from the inside, since the ends of these members would ignite sooner than combustibles in contact with the unexposed surface of the wall. Where the hollow spaces at the floor lines between the ends of the joists and the outside of the wall, and for not less than 4 inches above, below, and between them, are filled solid with incombustible fire-resistive materials, the fire resistance at the floor lines will be increased and combustible members in hollow tile walls will affect the fire resistance of only 8-inch walls with periods in excess of two hours. In party or fire walls that have combustible members framed in from both sides it is apparent that there must be no contact or hollow space between the members. A minimum of 4 inches of solid material should be provided between the ends of such members.

(b) INTERIOR EXPOSURE

(1) Interior Walls or Partitions.—Conditions of exposure are substantially the same as for party and fire walls separating attached buildings. Load-carrying ability under fire conditions is required where used for bearing purposes, and the requirements for stability would be the same as for exterior walls subjected to fire from within the building.

(2) Exterior Walls.—Here the main considerations are load-carrying ability and stability under fire conditions, in order that the wall may support the interior construction throughout the fire or until it collapses. The extent of protection afforded neighboring

buildings and fire-fighting operations is dependent upon the stability of the walls both before and after collapse of any combustible interior construction that may be supported on them. Where used as panel or curtain walls, the condition approximates that of the restrained walls in the test.

The tests of unrestrained walls give information on stability for one-story walls or the top-story walls of a higher building supporting a light or combustible floor or roof framing. The stability of multiple-story walls after interior construction has collapsed can not very well be determined in tests. The deflection varies with the square of the unsupported height, and collapse of portions of walls of the thinner thicknesses is to be expected at the time or subsequent to the collapse of interior framing. The unrestrained hollow-tile walls in these tests developed no higher deflections than solid-masonry walls in similar tests.

Since the fire resistance of exterior walls subjected to an interior fire is not determined by temperature transmission, combustible members framing into them affect their fire resistance only in decreasing their stability if collapse of interior framing takes place.

Where used with fire-resistive interior construction, heavier wall thicknesses or protections for both interior and exterior walls are justified than with combustible or unprotected interior framing, since after the fire the wall should be able to support the interior construction and be in a condition that will permit making it safe for further use with proper repairs. Increasing the wall thickness or applying protections beyond the bare requirements of the load and fire conditions premised is a certain method by which the amount of repairs necessary after the fire can be reduced.

3. SIGNIFICANCE OF FIRE-RESISTANCE CLASSIFICATIONS

The fire-resistance periods are based on ability to carry load for the given periods and to prevent transmission of flame or temperatures high enough to endanger combustible materials in contact with the unexposed side of the wall or combustible members projecting into it. Individual municipalities or users of tile can obtain structural fire protection corresponding to any of the classifications given in Table 20 by proper building-code and specification requirements, supplemented by examination and tests of the products submitted for use. This procedure will add little to the inspection details needed to determine whether tile within any of the fire-resistance classifications meets ordinary specification requirements in point of strength, weight, and porosity, since the difference between the classifications is mainly one of design, and the latter becomes known when the other properties are determined. By further identification of the material available in a given locality, particularly as it concerns

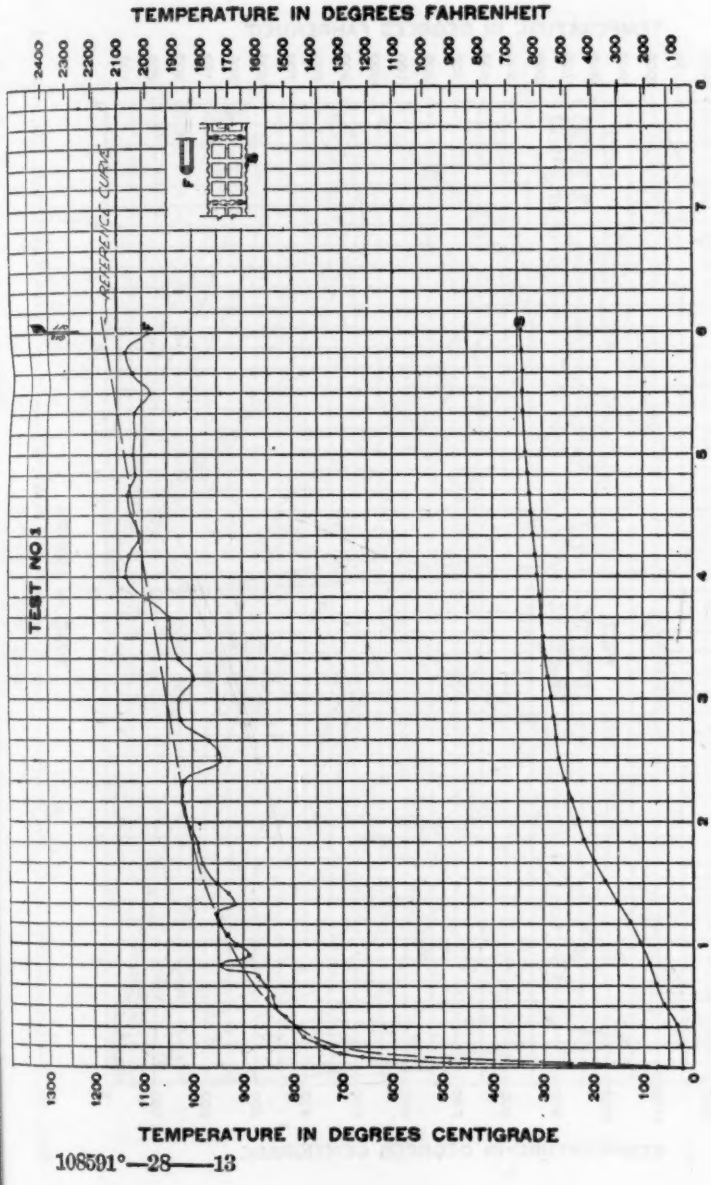
the type of clay used, it may be possible to base specification and building-code requirements on the more detailed results given in Table 19, with some gain in the precision with which the products will meet stipulated fire-resistance requirements.

4. FIRE DAMAGE

The amount of fire damage incurred within the rated resistance period of the construction and, to some extent, that incurred with fire exposure or load application beyond the rated resistance is of interest to the building owner and the carrier of his fire risk. This has been detailed and correlated with the properties of the raw material and finished product that govern its extent. Several details of design or manufacture and methods of application have been shown effective in various degrees in decreasing the fire damage. The scope of this portion of the work was kept within the bounds dictated by present manufacturing practice and ordinary methods of application of the product in buildings. Even within the bounds of this limitation, effectiveness up to almost complete immunity from fire damage was proven possible and under many conditions practicable.

5. FIRE RESISTANCE IN RELATION TO OTHER PROPERTIES

The choice of a material for a given purpose depends on many considerations, of which fire resistance is only one. Fire is a contingent condition that may or may not involve a building, or a given portion thereof, during its existence. Fire resistance has a range in meanings from relative incombustibility to immunity from damage in severe fires. Modern fire-resistive building construction, as well as the general community fire hazard in built-up localities, imposes certain requirements for materials and constructions used for given purposes and in given locations, the main outlines of which have been given above as far as it concerns wall constructions. Assuming these to have been satisfactorily met, the degree of fire resistance generally obtainable beyond this limit will depend on the extent to which materials and methods of applications yielding this higher protection comply with the other purposes and conditions governing in each case. For masonry wall and partition materials the latter would include in part strength, permanence, weathering resistance, insulation against moisture, heat, and cold; acoustic properties; ability to take plaster, stucco, or other finish; freedom from shrinkage and cracking; esthetic or architectural effects, availability, and cost. The work reported in this paper concerns the one property only, and the authors express the hope that the information developed will be helpful in securing safe and economical application of the material wherever, as determined by all considerations involved, its use is deemed advantageous.



108591°—28——13

FIG. 56.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell shale tile, source d, test No. 1*

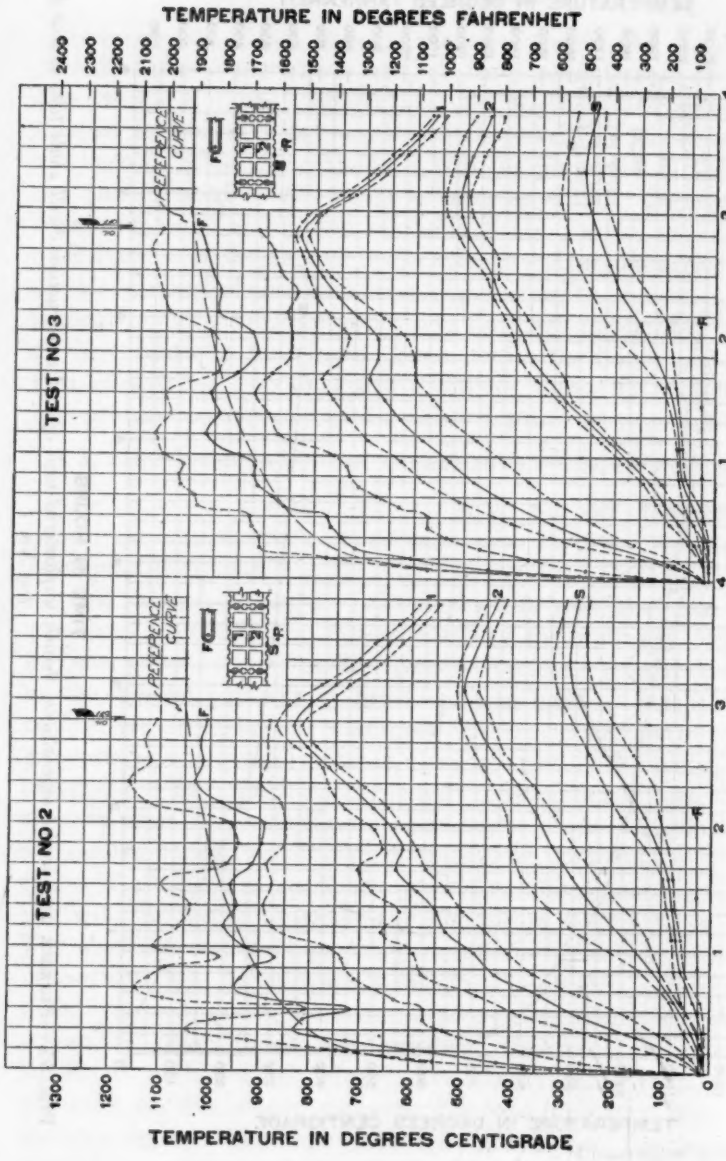


FIG. 57.—*Furnace and wall temperatures, 8-inch unplastered walls of end construction 6-cell shale tile, source d, tests Nos. 2 and 3*

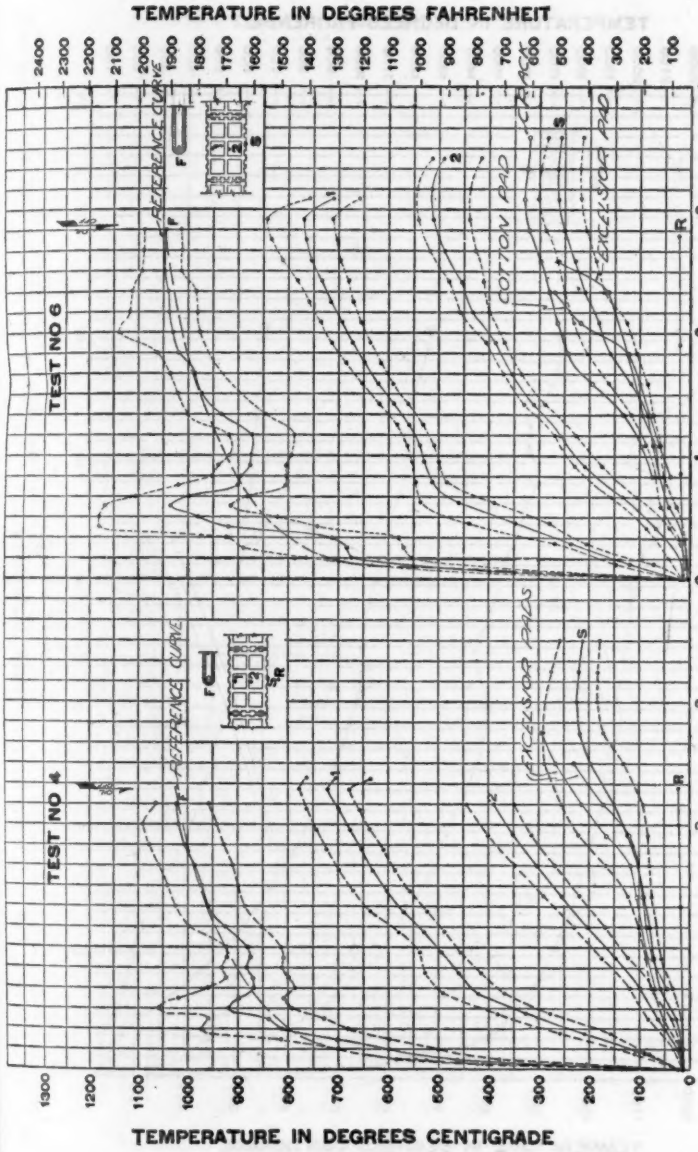


FIG. 58.—*Furnace and wall temperatures, 8-inch unplastered walls of end construction 6-cell shale tile, source d, tests Nos. 4 and 6*

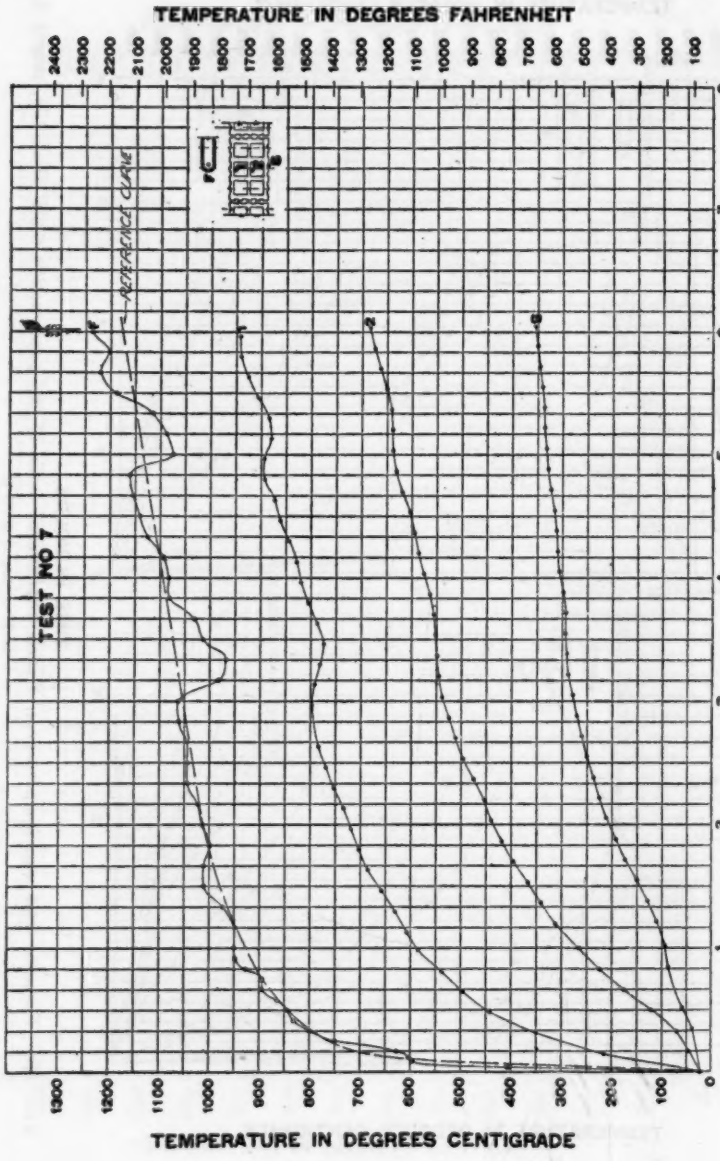


FIG. 59.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell shale tile, source a-1, test No. 7*

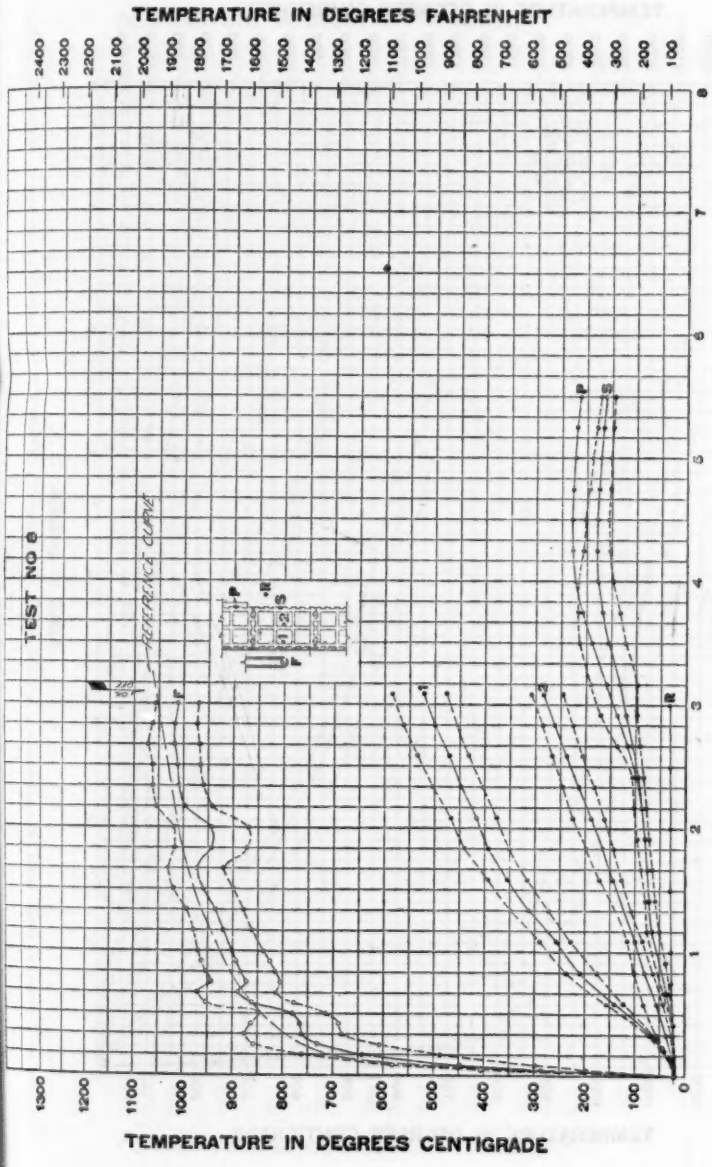


FIG. 60.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell shale tile, source d, set on side, gypsum plaster on fire side, test No. 8*

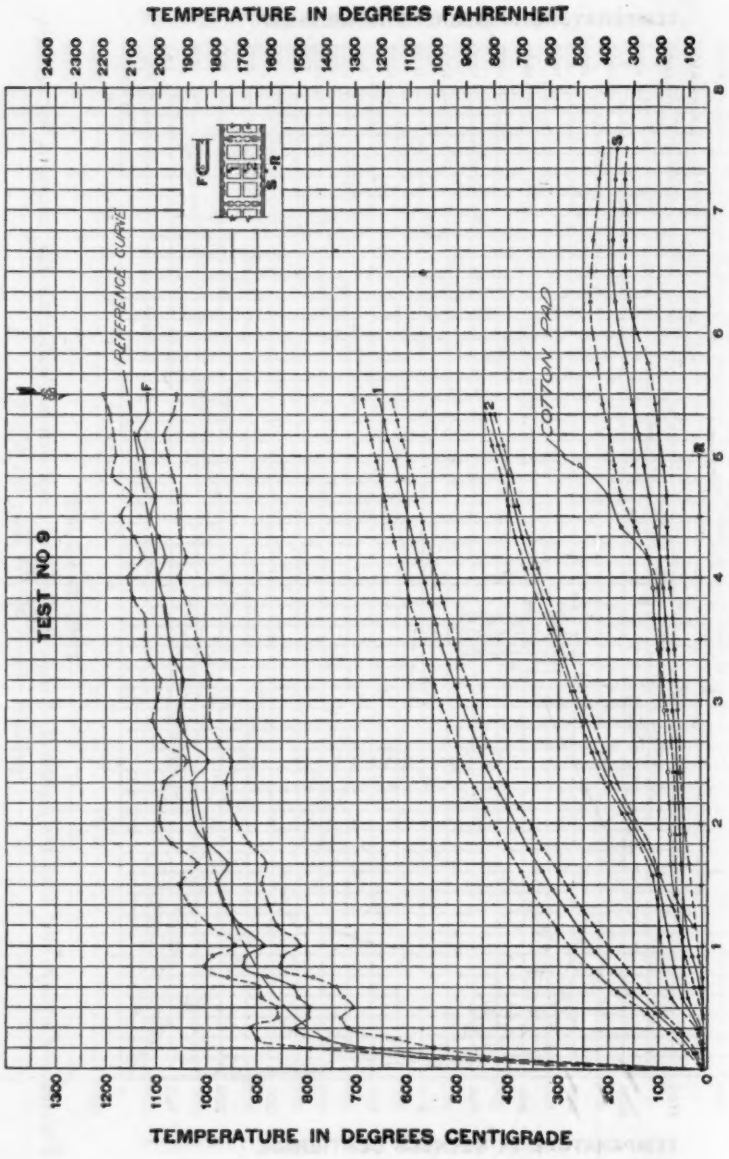


FIG. 61.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell shale tile, source d, gypsum plaster both sides, test No. 9*

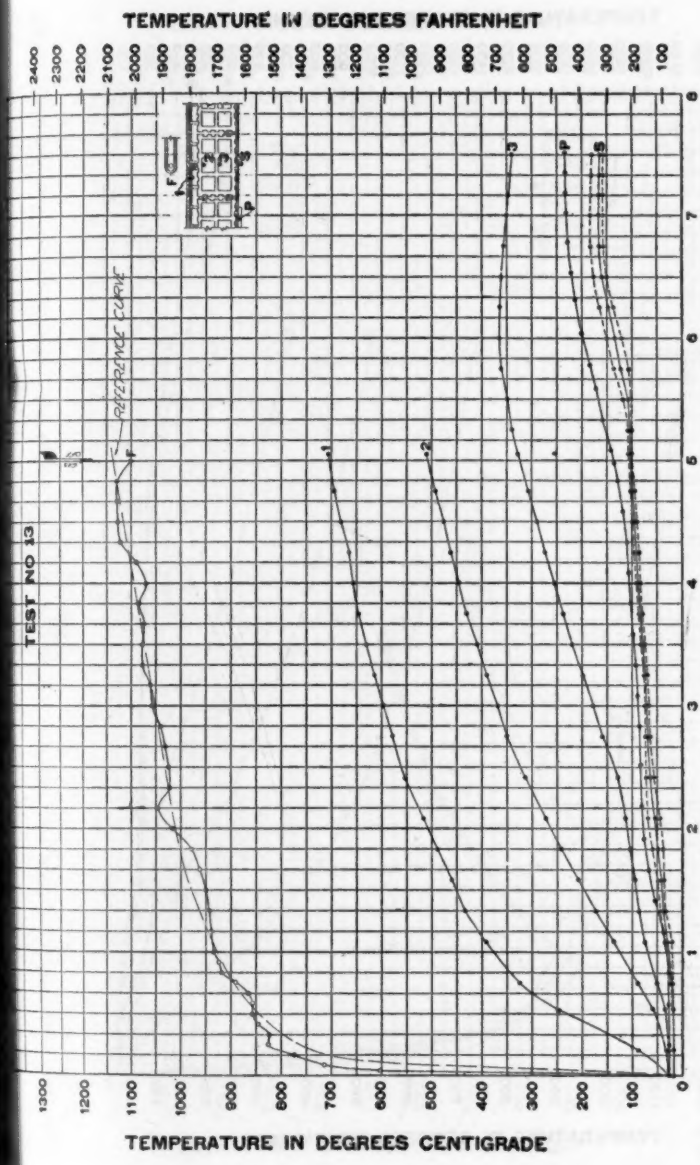


FIG. 62.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell shale tile, source d, furred on fire side, gypsum plaster both sides, test No. 13*

FIG. 61.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell shale tile, source d, furred on fire side, gypsum plaster both sides, test No. 9*

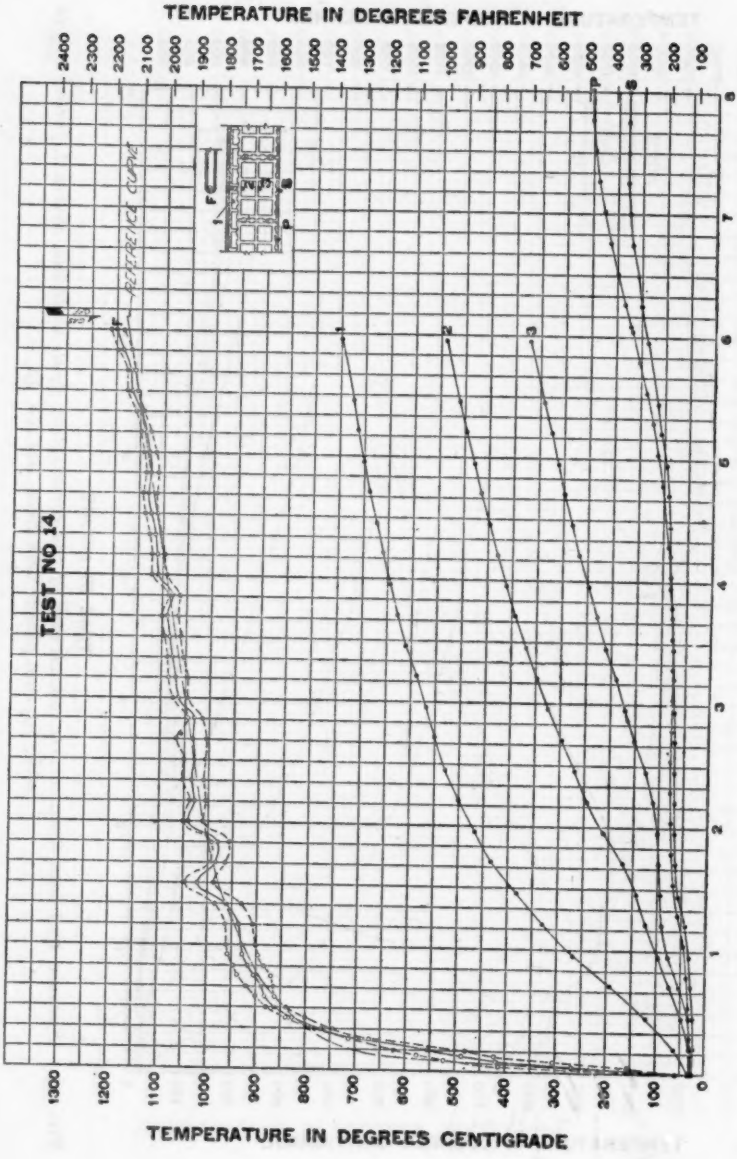


FIG. 63.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell shale tile, source d, furred on fire side, gypsum plaster both sides, test No. 14*

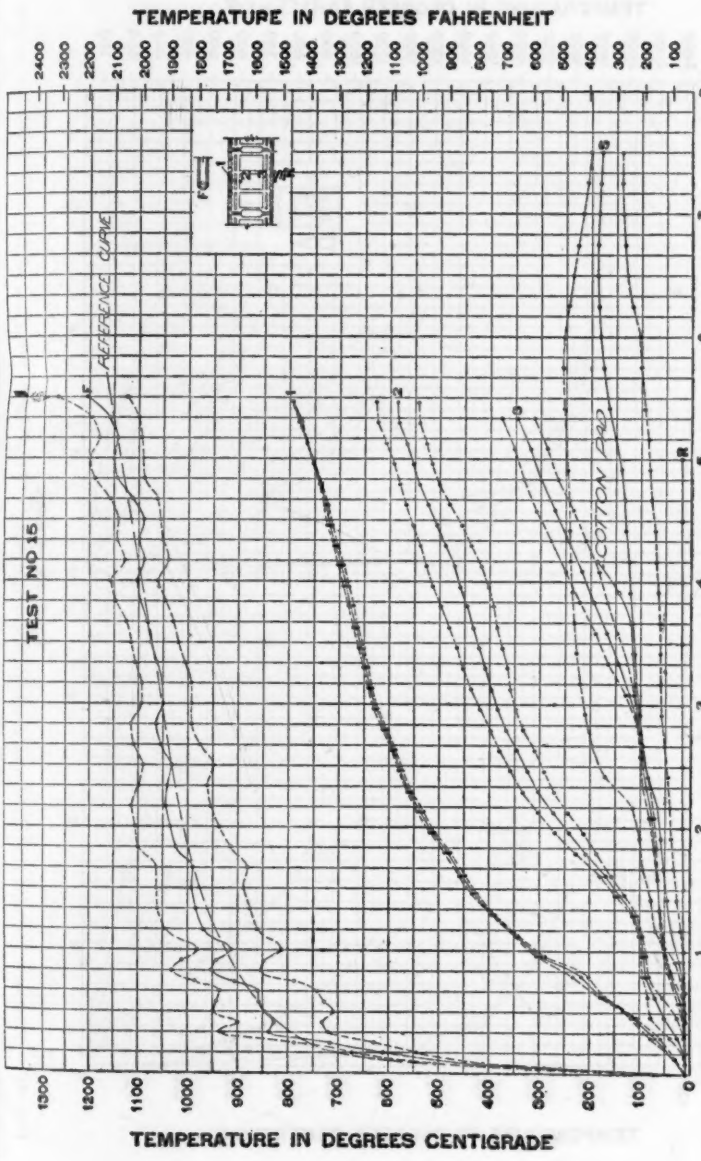


FIG. 64.—*Furnace and wall temperatures, 8-inch wall of end construction double shell shale tile, source d, gypsum plaster both sides, test No. 15*

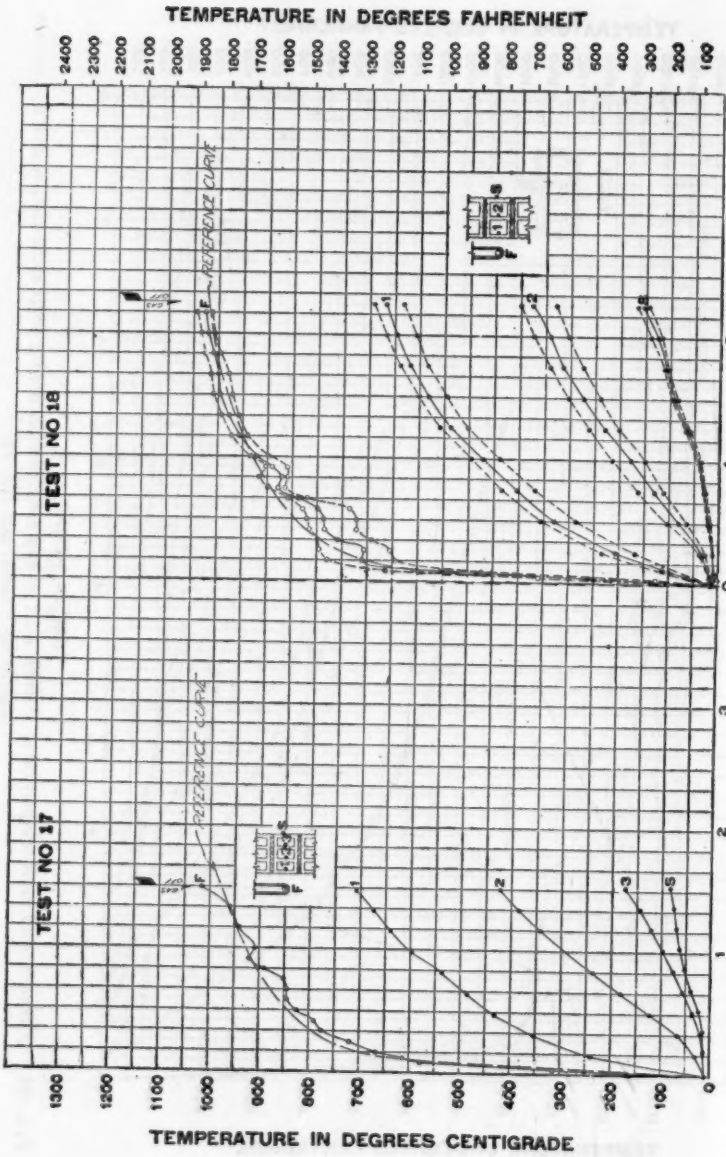


FIG. 65.—*Furnace and wall temperatures, 8-inch unplastered wall of 8 by 5 inch side construction 3-cell shale tile, source C, test No. 17; 8-inch unplastered wall of 8 by 5 inch side construction 2-cell shale tile, source A-2, test No. 18*

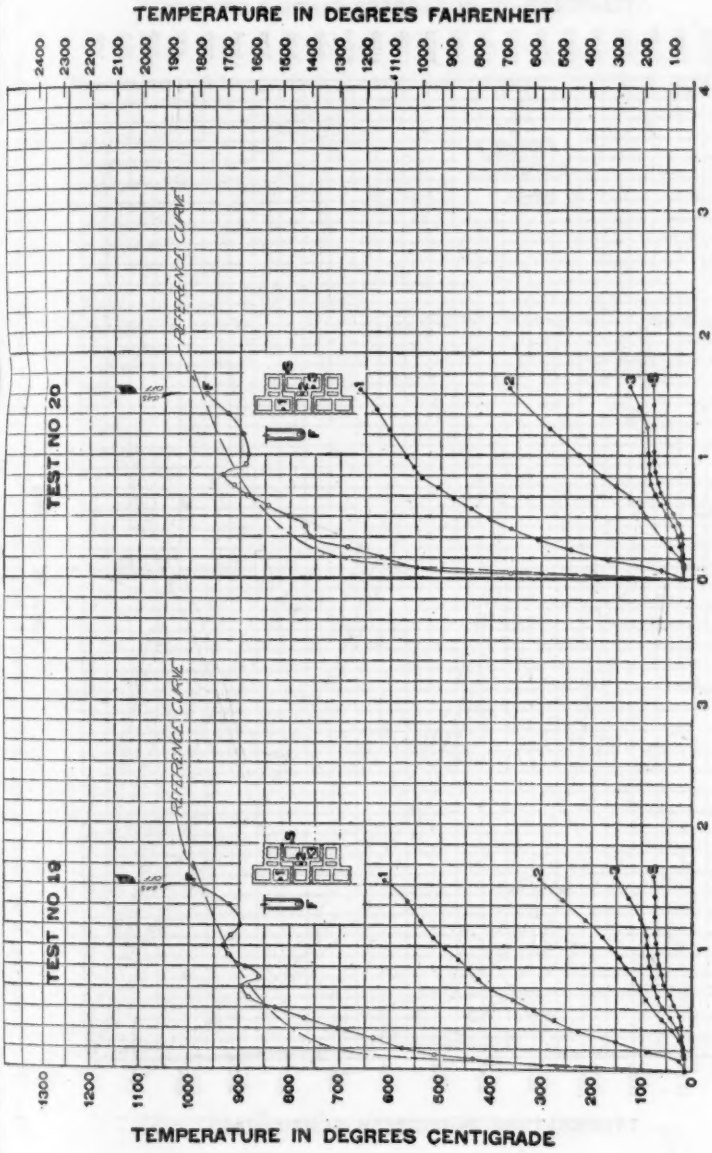


FIG. 66.—*Furnace and wall temperatures, 8-inch unplastered walls of side construction interlocking shale tile, source d–1, tests Nos. 19 and 20*

FIG. 65.—*Furnace and wall temperatures, 8-inch unplastered wall of 8 by 5 inch side construction 3-cell shale tile, source c, test No. 17; 8-inch unplastered wall of 8 by 5 inch side construction 3-cell shale tile, source d–2, test No. 18*

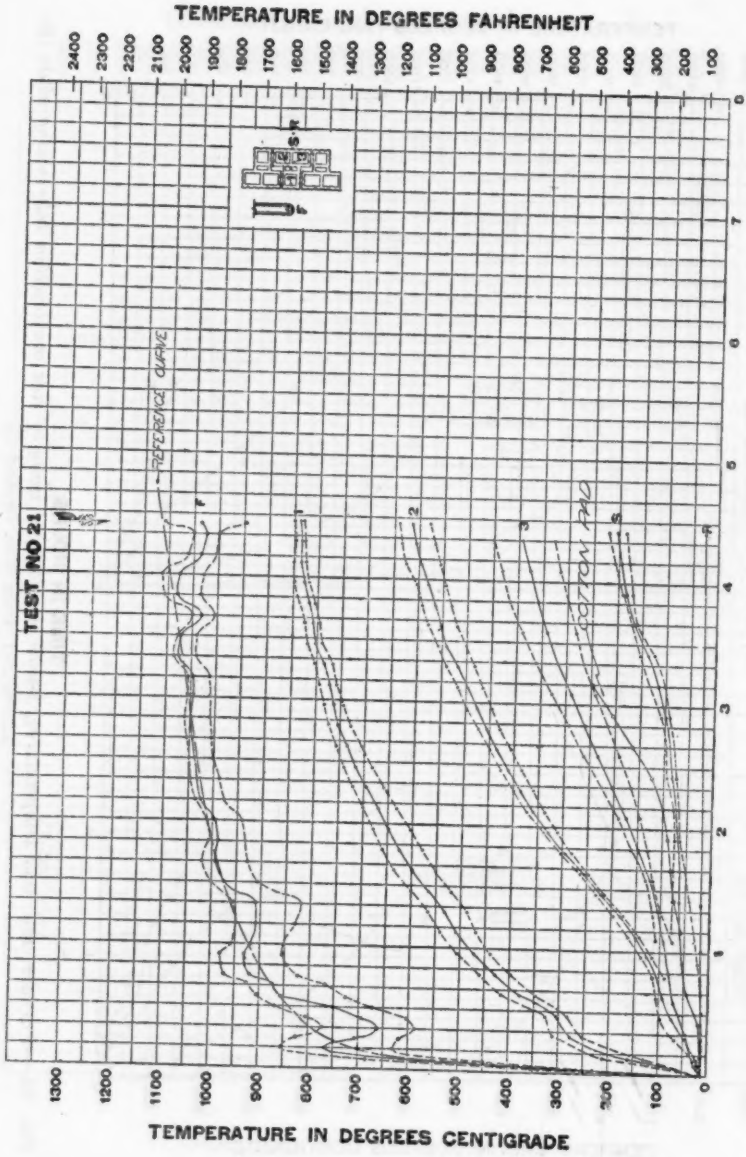


FIG. 67.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction interlocking shale tile, source d–1, test No. 21*

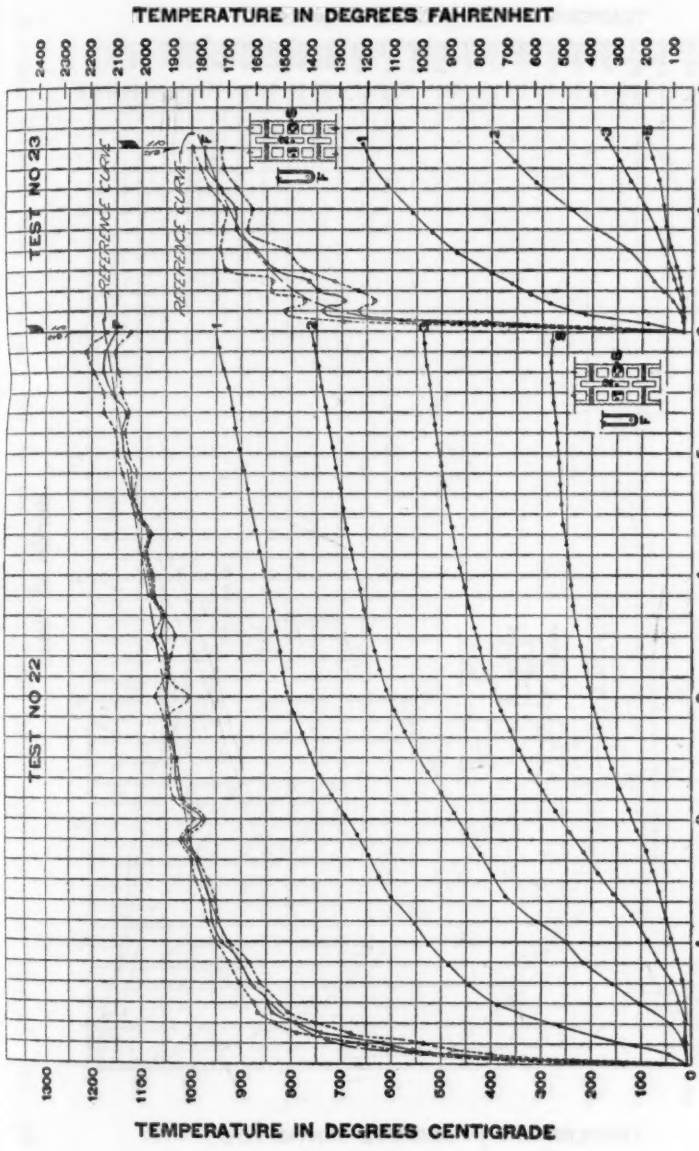


FIG. 68.—*Furnace and wall temperatures, 8-inch unplastered walls of side construction* H *shaped shale tile, source c–1, tests Nos. 22 and 23*

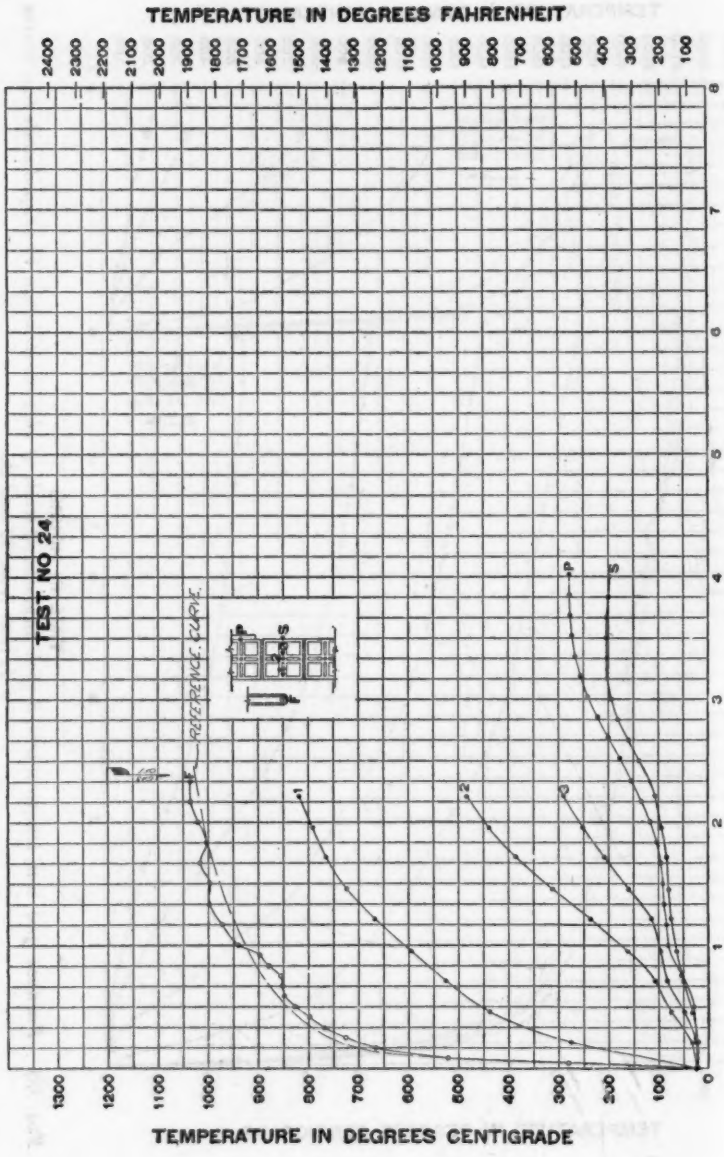


FIG. 69.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction cube shale tile, source d, test No. 24*

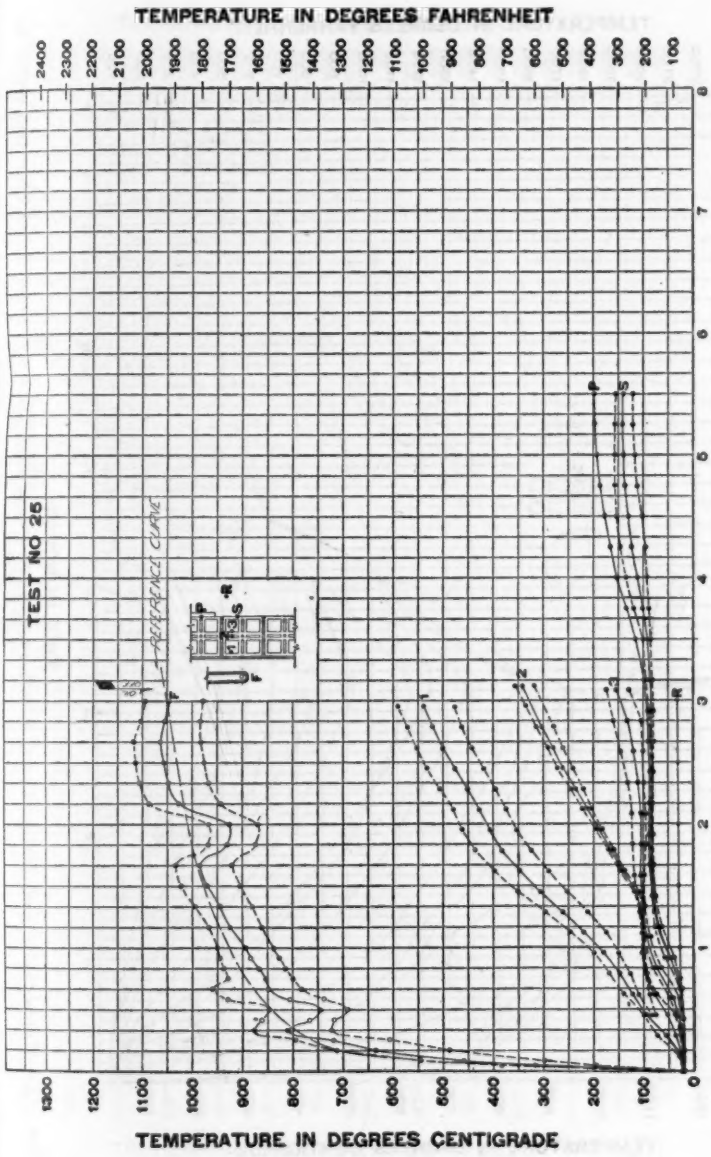


FIG. 70.—*Furnace and wall temperatures, 8-inch wall of side construction cube shale tile, source d, gypsum plaster fire side, test No. 25*

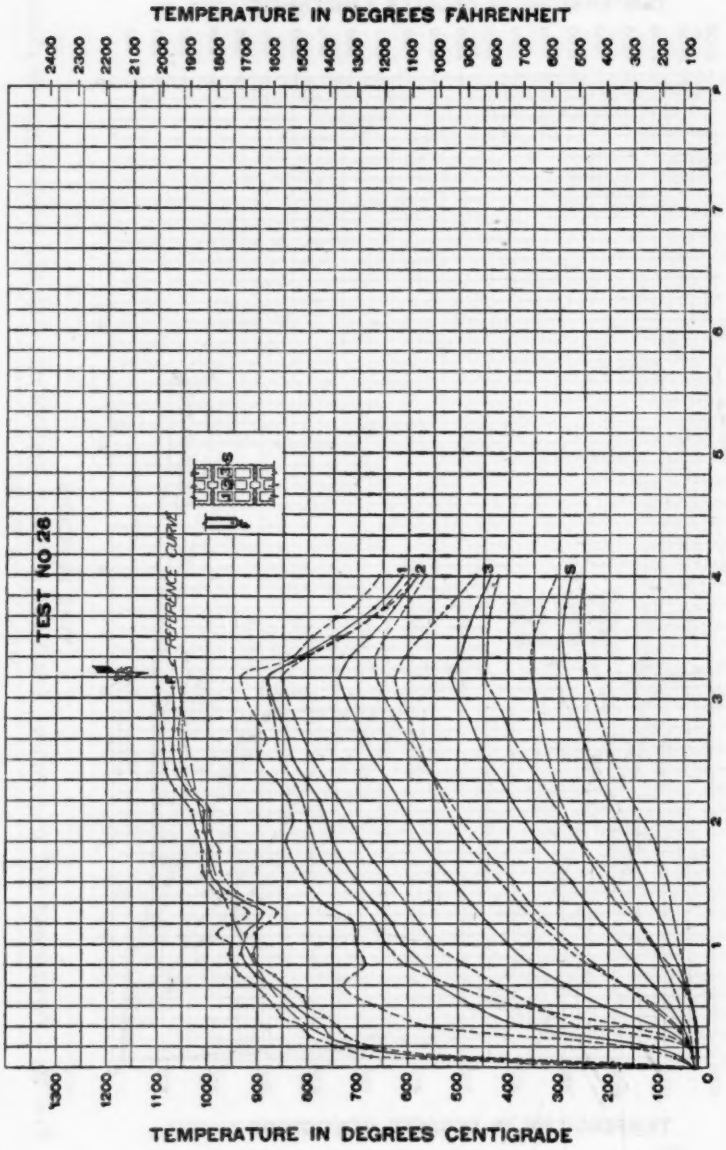


FIG. 71.—*Furnace and wall temperatures, 8-inch unplastered wall of 8 by 8 inch side construction shale tile, source a, test No. 26*

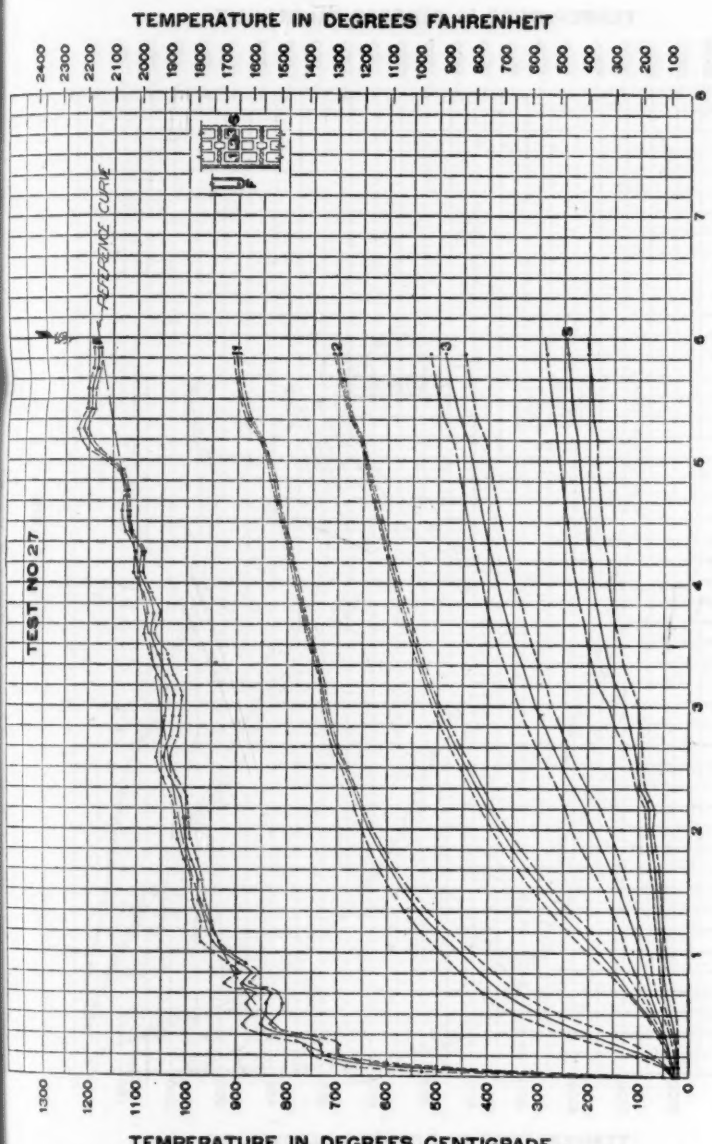


FIG. 72.—*Furnace and wall temperatures, 8-inch wall of 8 by 8 inch side construction shale tile, source a, gypsum plaster fire side, test No. 27*

108591°—28——14

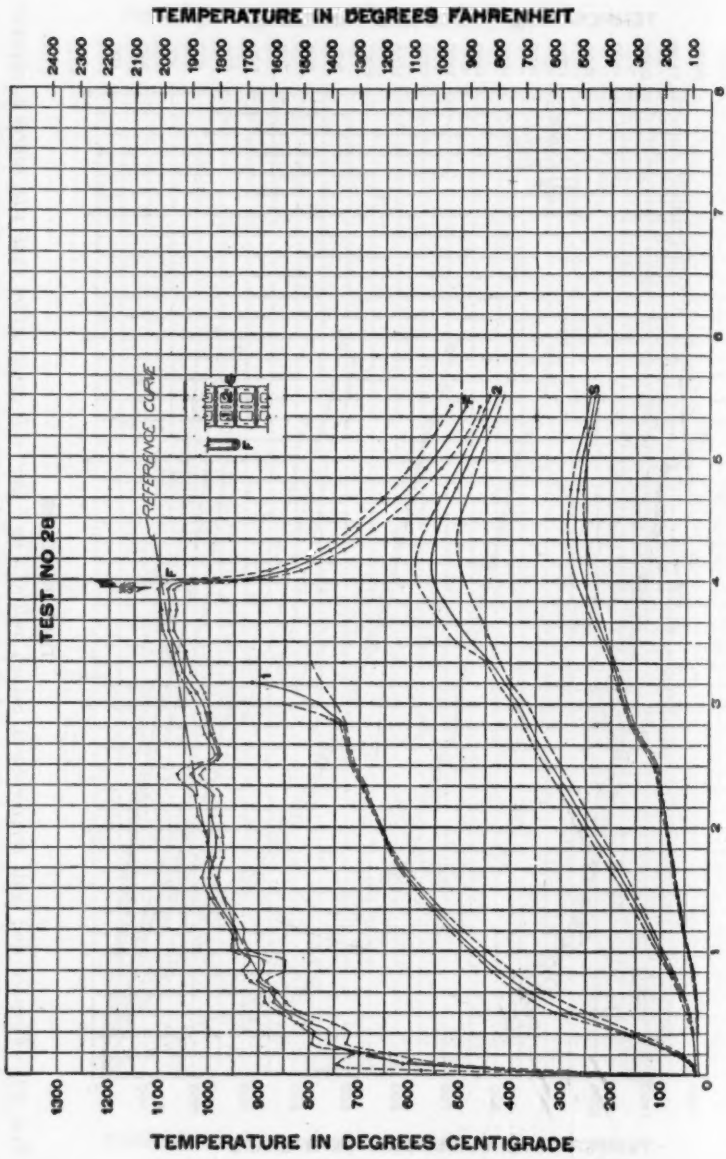


FIG. 73.—*Furnace and wall temperatures, 8-inch unplastered wall of 8 by 3½ inch side construction 8-cell shale tile.*

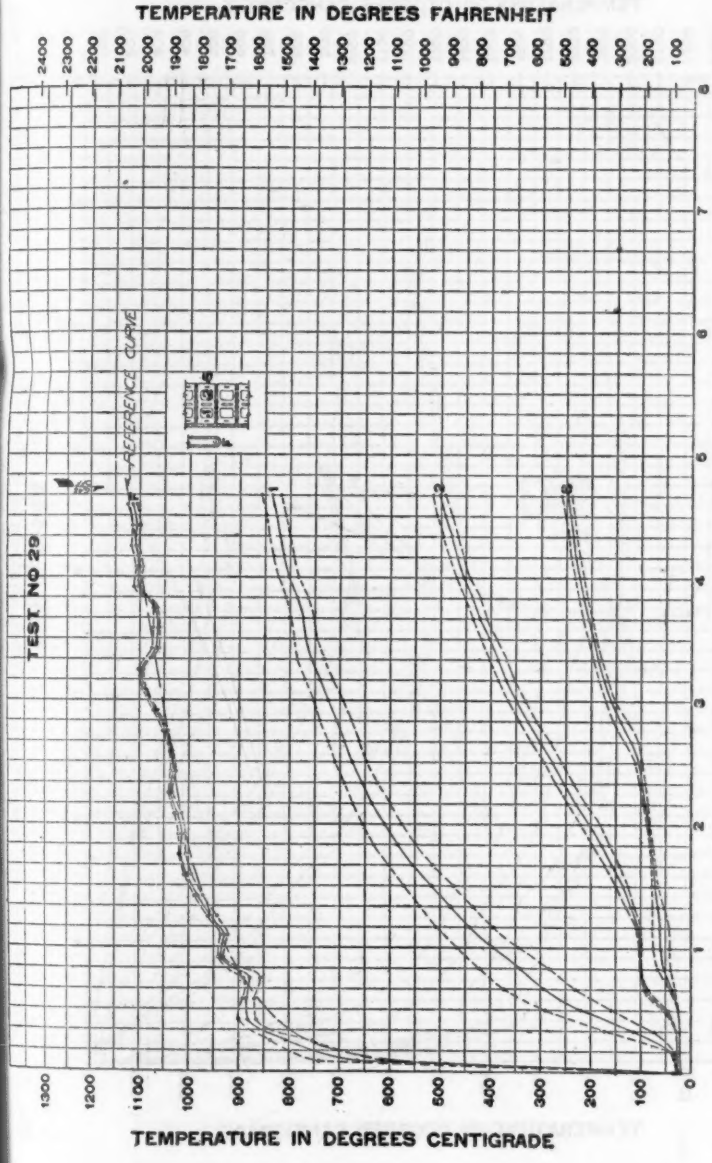


FIG. 74.—*Furnace and wall temperatures, 8-inch wall of 8 by 3½ inch side construction 3-cell shale tile, source d–3, gypsum plaster fire side, test No. 29*

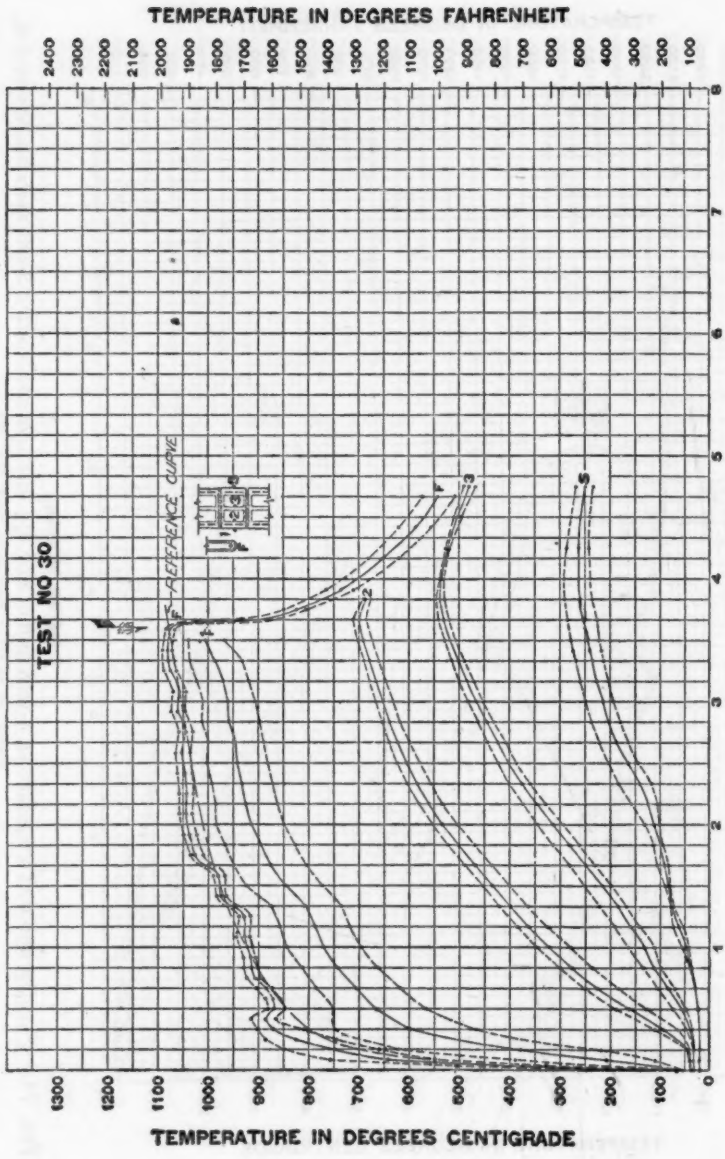


FIG. 75.—*Furnace and wall temperatures of 8-inch unplastered wall of 8 by 5 inch side construction double shell hollow tile, source of B. test No. 30*

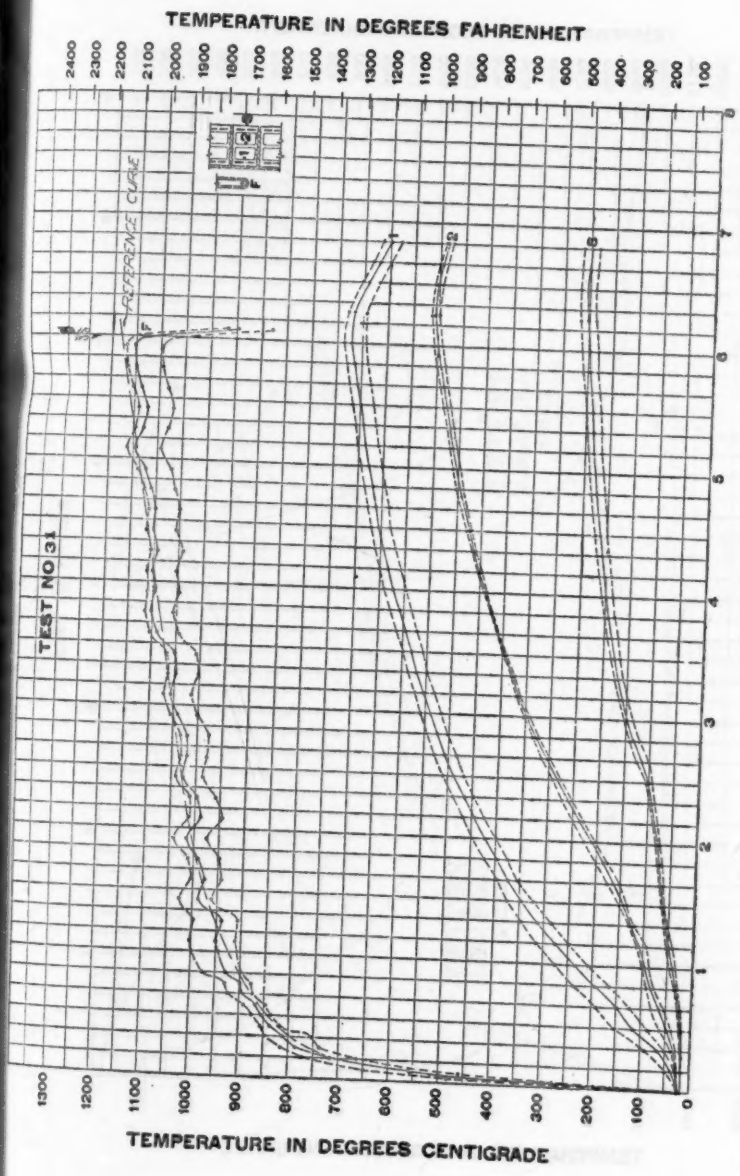


FIG. 76.—*Furnace and wall temperatures, 8-inch wall of 8 by 5 inch side construction double shell shale tile, source d–3, gypsum plaster fire side, test No. 31*

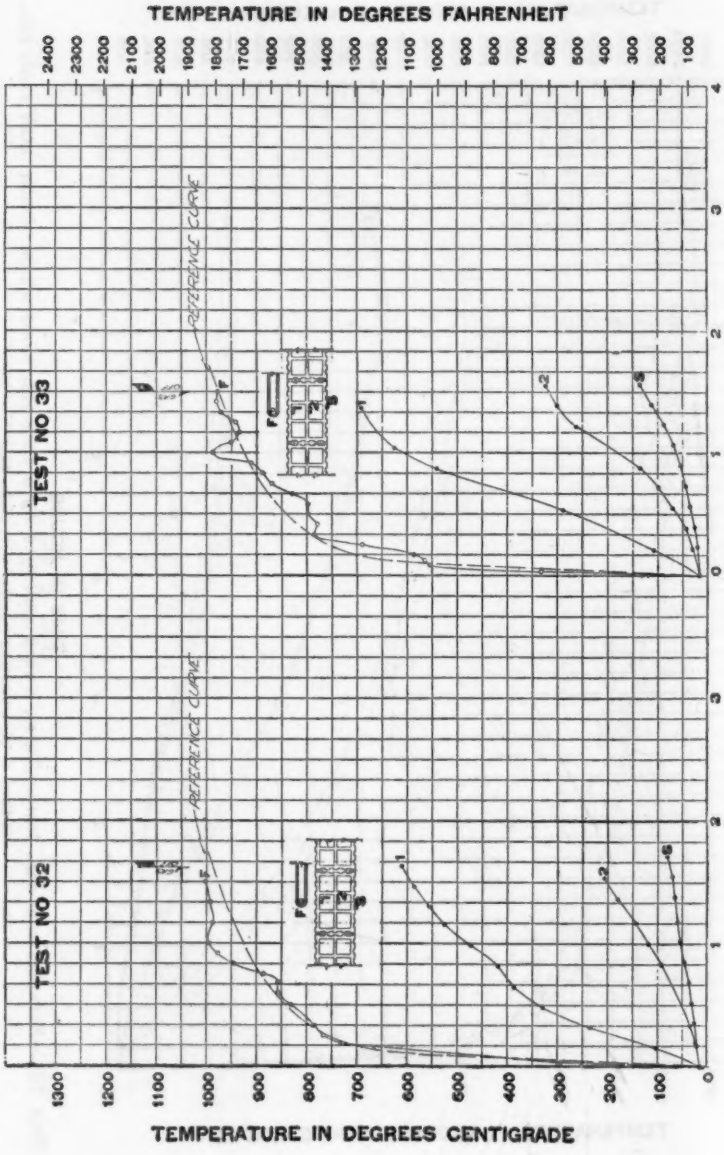


FIG. 77.—*Furnace and wall temperatures, 8-inch unplastered walls of end construction 6-cell surface clay tile, source j, test Nos. 32 and 33*

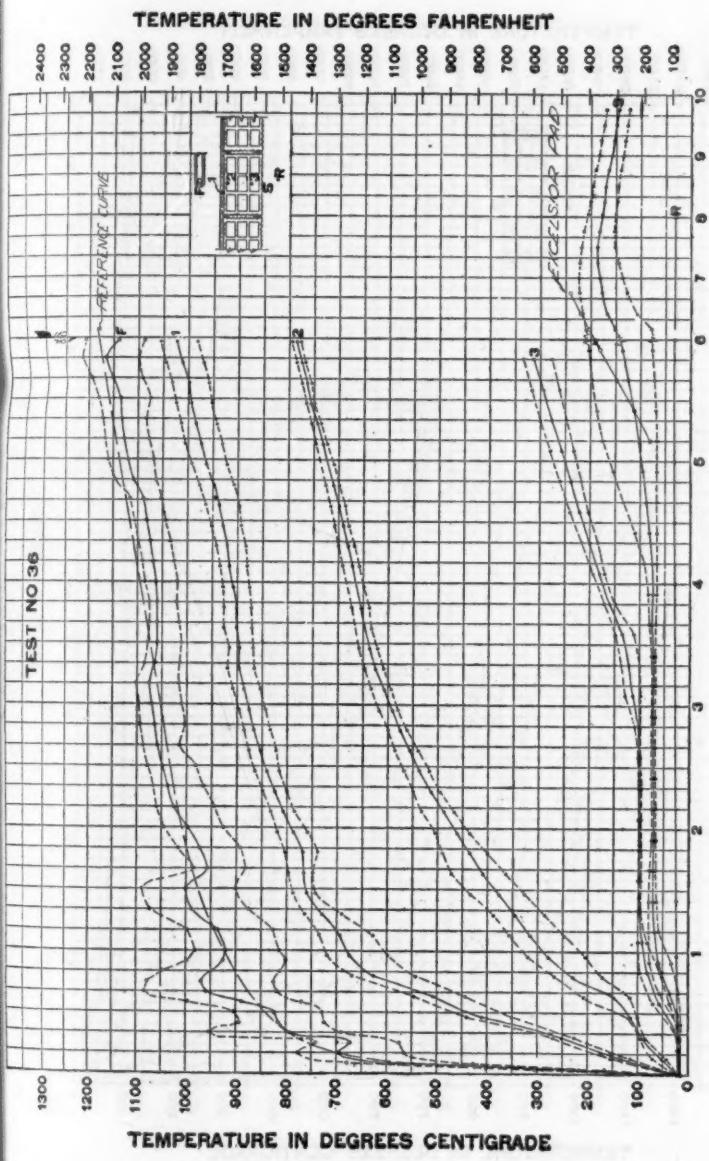


FIG. 78.—*Furnace and wall temperatures, 8-inch wall of end construction 9-cell surface clay tile, source j, gypsum plaster fire side, test No. 36*

FIG. 77.—*Furnace and wall temperatures, 8-inch unplastered walls of end construction 6-cell surface clay tile, source j, test Nos. 32 and 33*

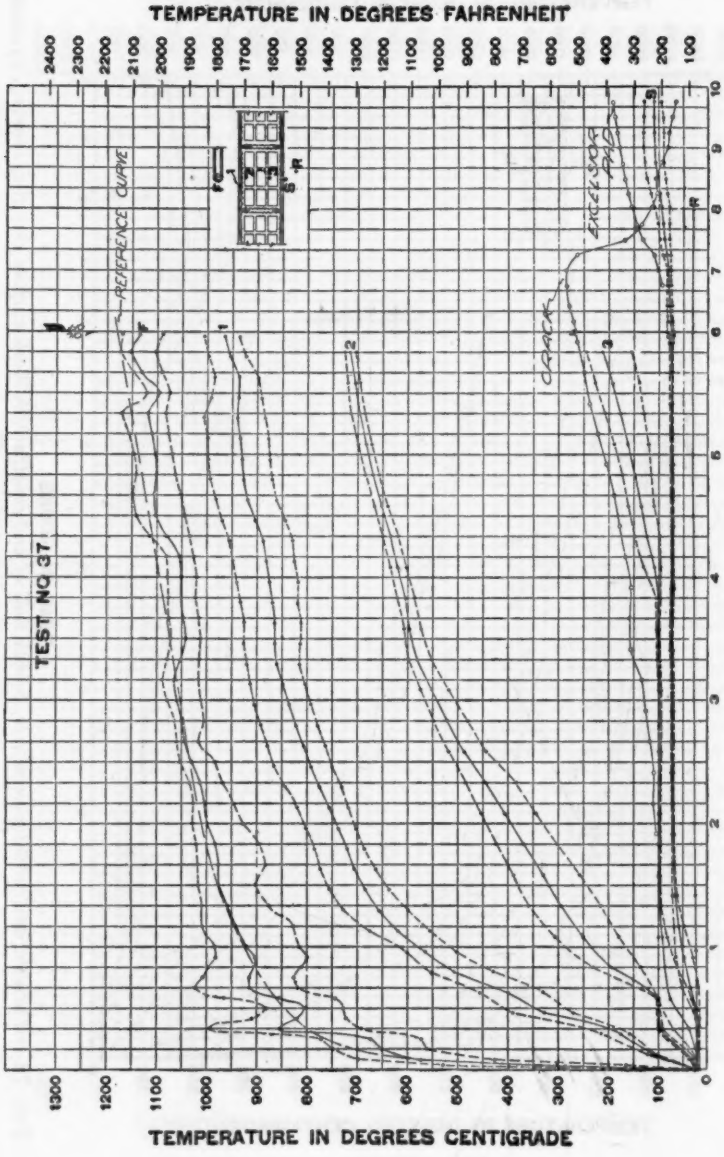


FIG. 70.—*Furnace and wall temperatures, 8-inch wall of end construction 9-cell surface clay tile, source j, cement*

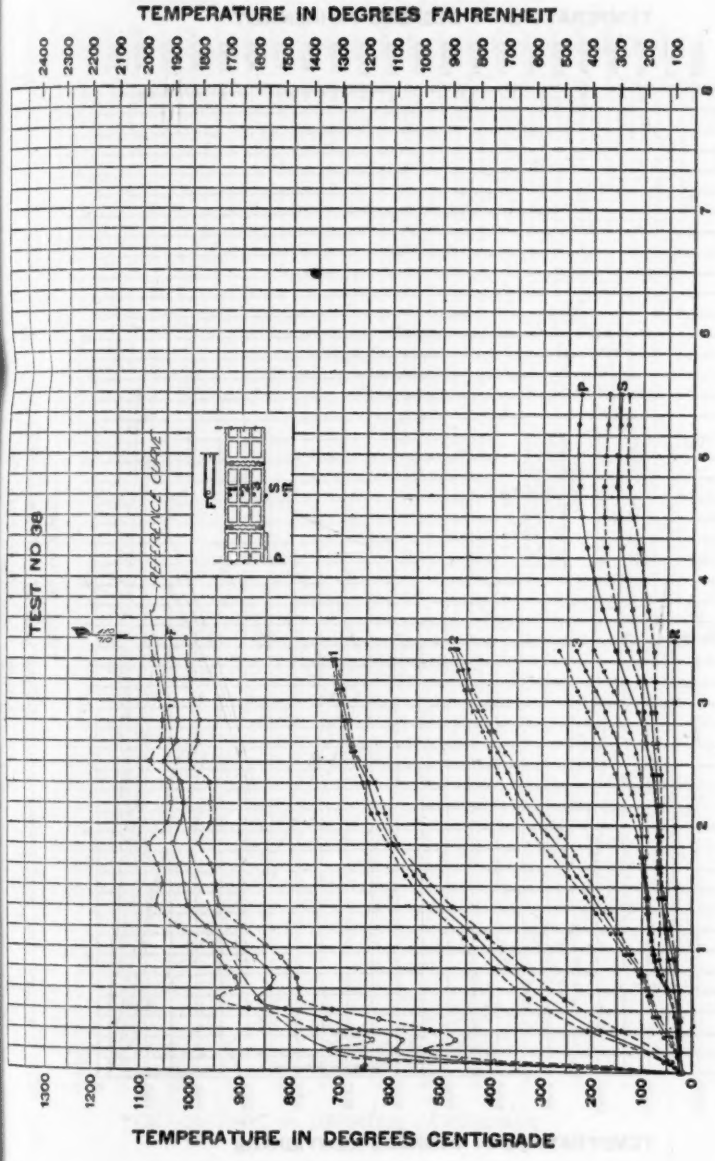


Fig. 80.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 9-cell surface clay tile, source j, test No. 38*

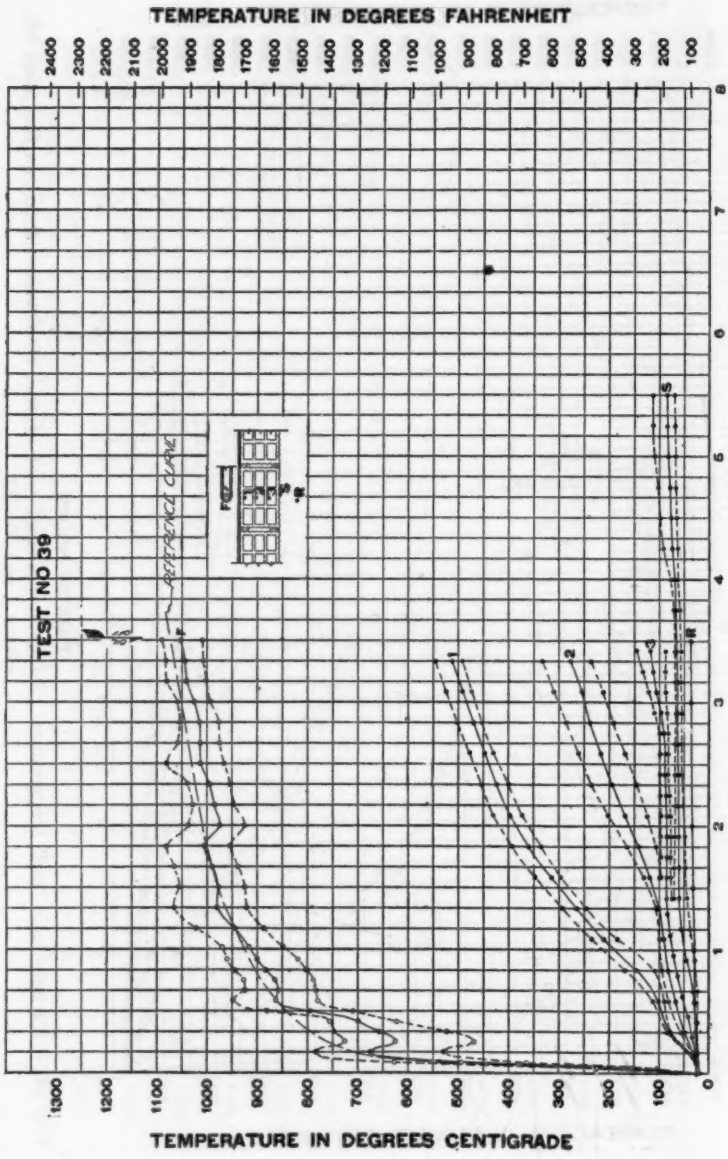


FIG. 81.—*Furnace and wall temperatures, 8-inch wall of end construction 9-cell surface clay tile, source j, gypsum plaster fire side, test No. 39*

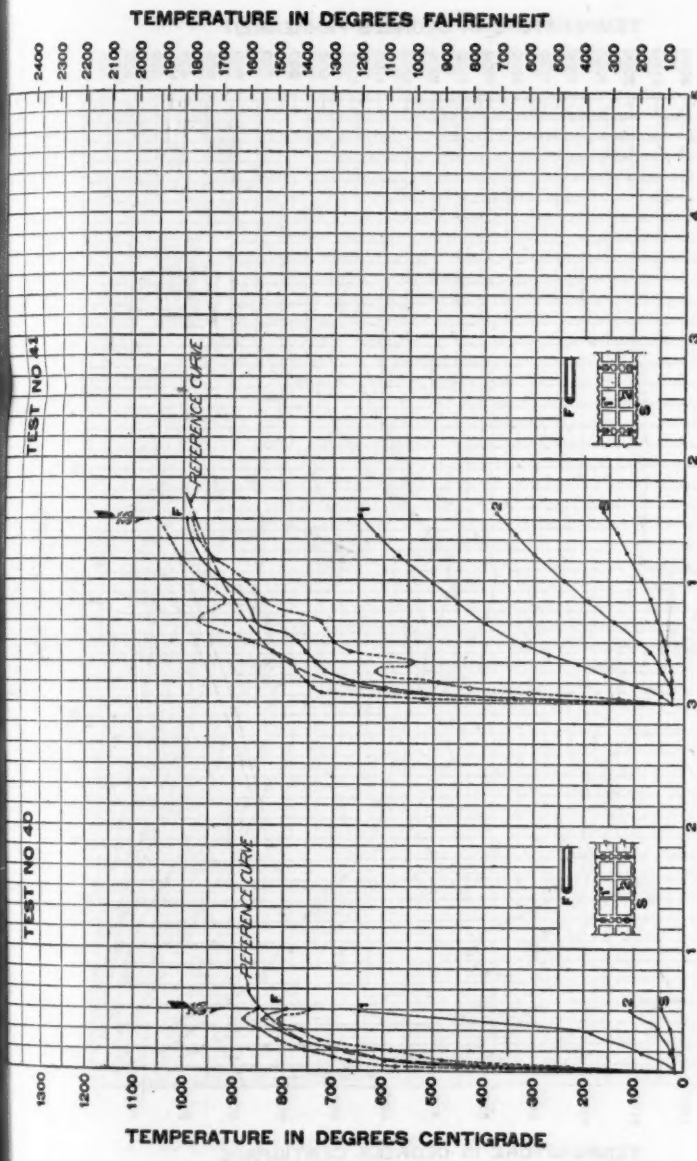


FIG. 82.—*Furnace and wall temperatures, 8-inch unplastered walls of end construction 6-cell surface clay tile, source r, tests Nos. 40 and 41*

FIG. 81.—*Furnace and wall temperatures, 8-inch wall of end construction 9-cell surface clay tile, source j, gypsum plaster fire side, test No. 39*

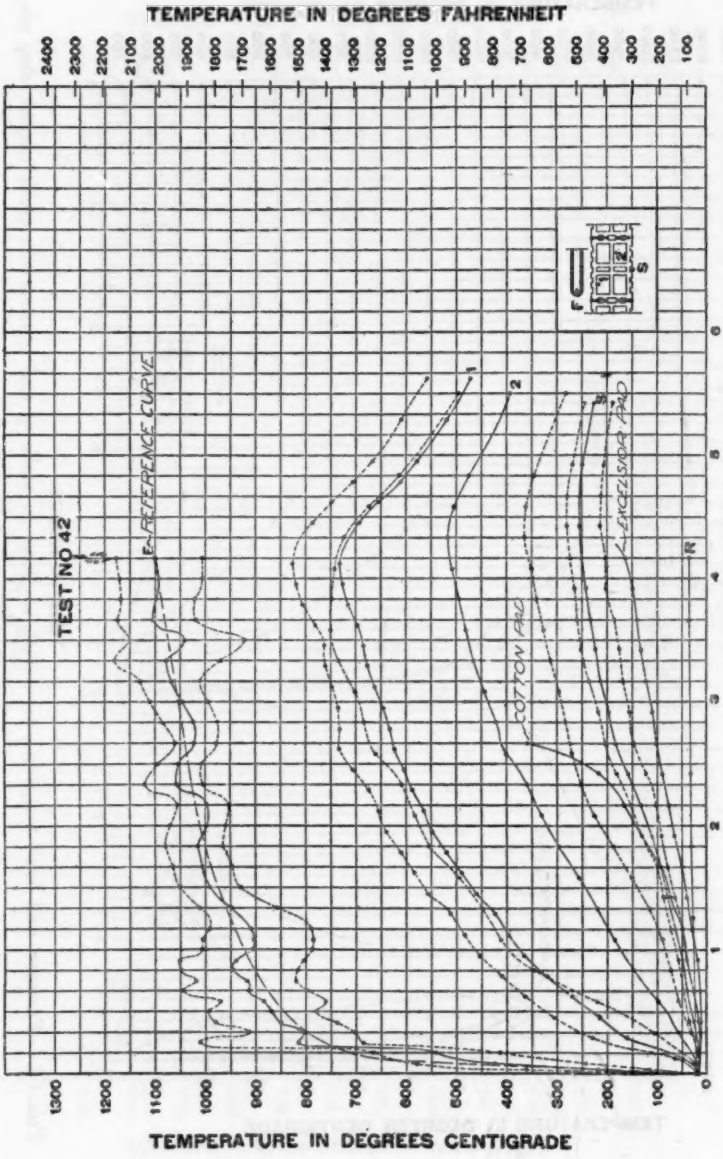


FIG. 83.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell "sze" surface clay tile, source L, test No. 42*

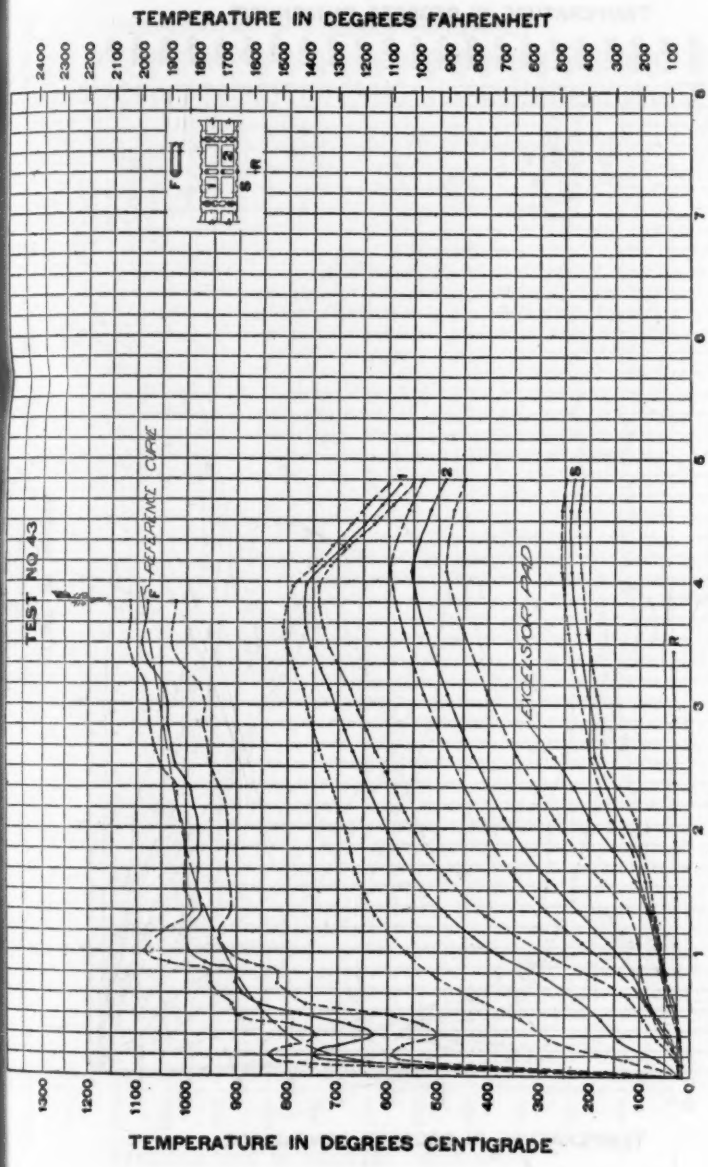


FIG. 83.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell "xx" surface clay tile, source k, test No. 43*

FIG. 84.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell "xx" surface clay tile, source k, test No. 43*

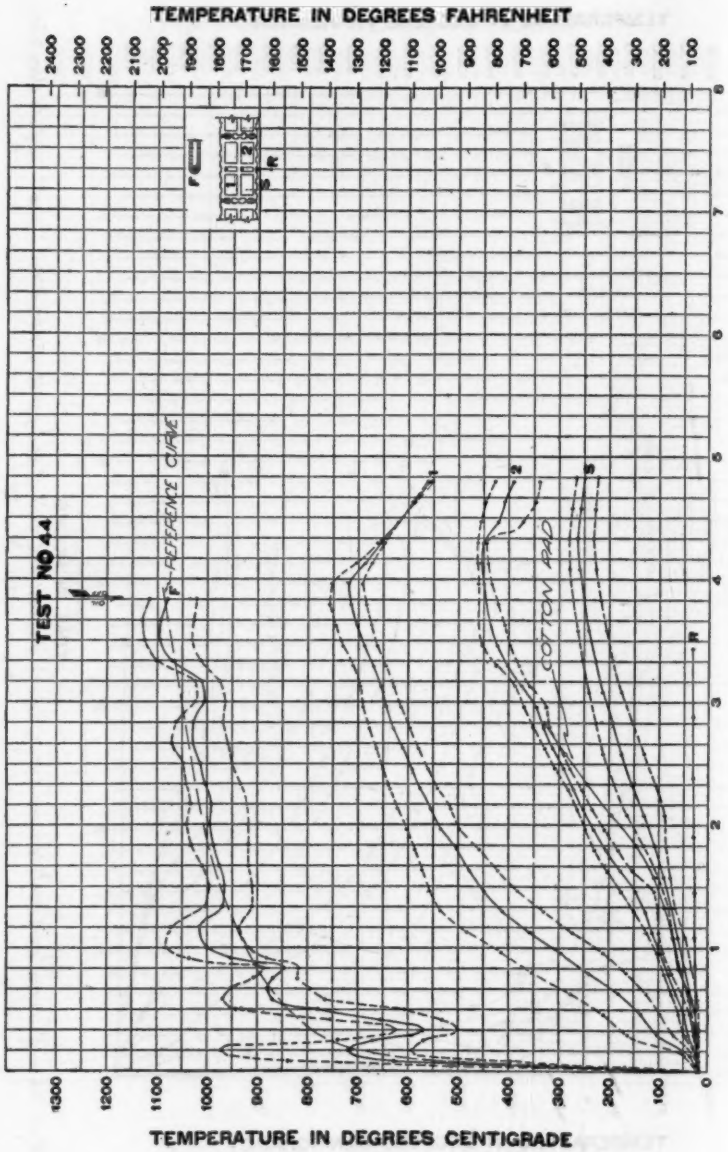


FIG. 85.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell "xx" surface clay tile, source k, test No. 44*

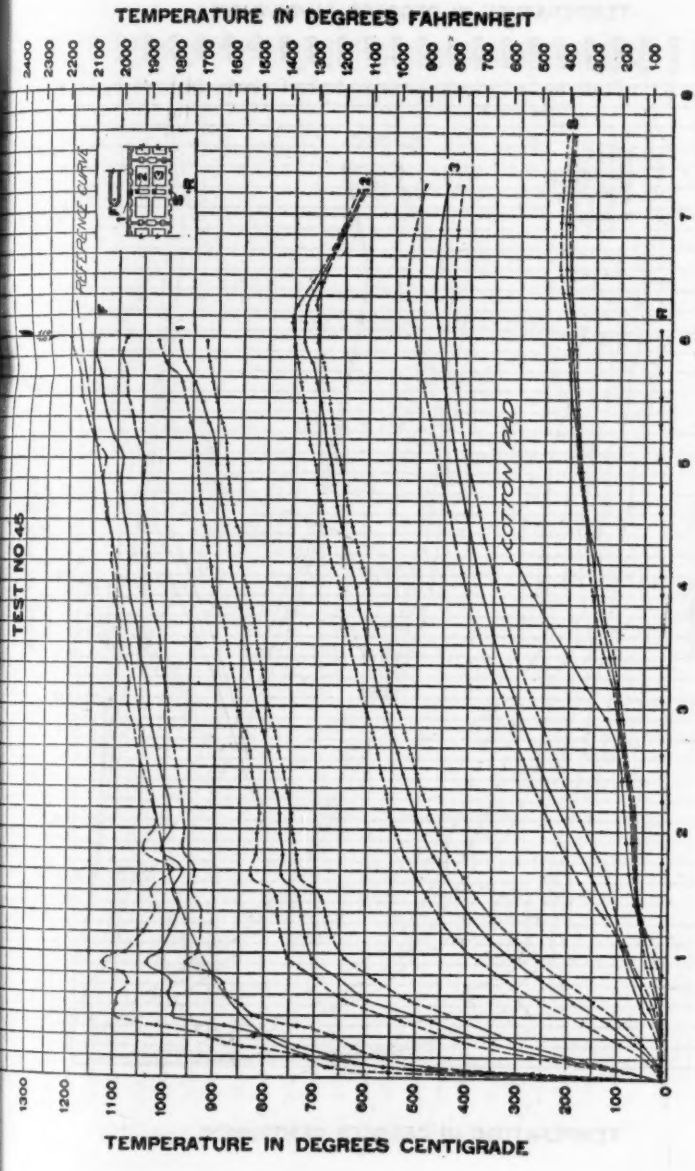


FIG. 86.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell "xx" surface clay tile, source k, gypsum plaster fire side, test No. 45*

FIG. 85.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell "xx" surface clay tile, source k, test No. 44*

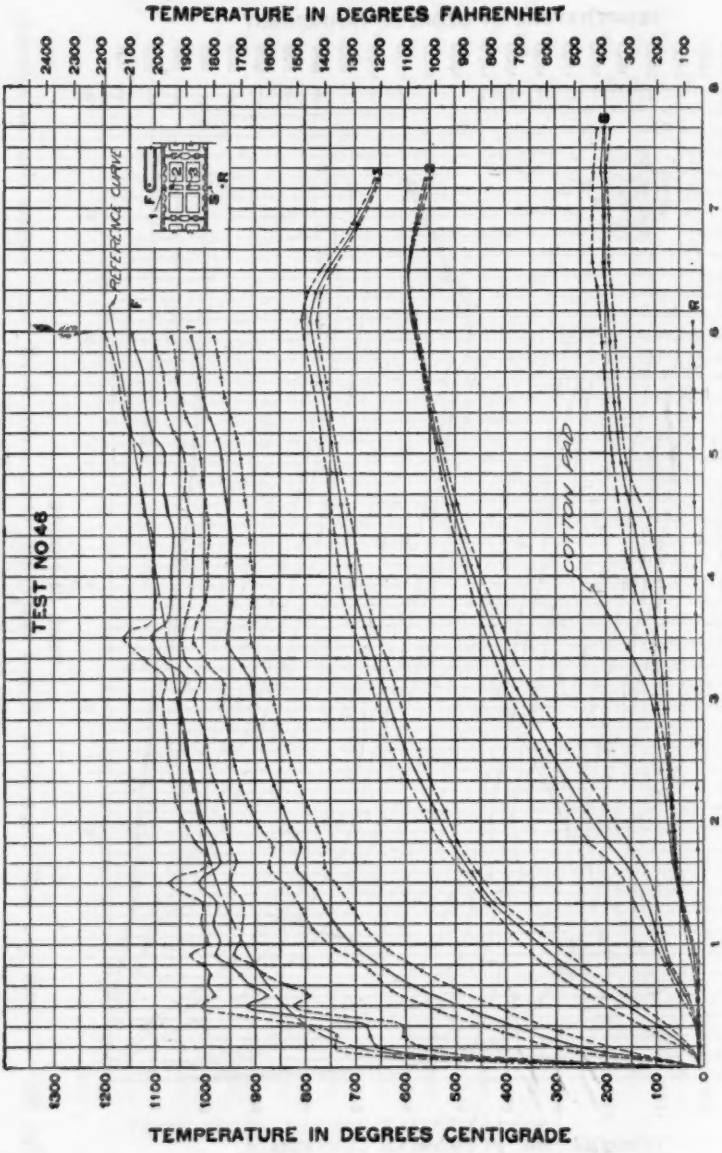


FIG. 87.—*Furnace and wall temperatures, 8-inch wall of end construction, 6-cell "xx" surface clay tile, source k.*

108591°—28——15

TIME IN HOURS

FIG. 87.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell "xxx" surface clay tile, source k.*

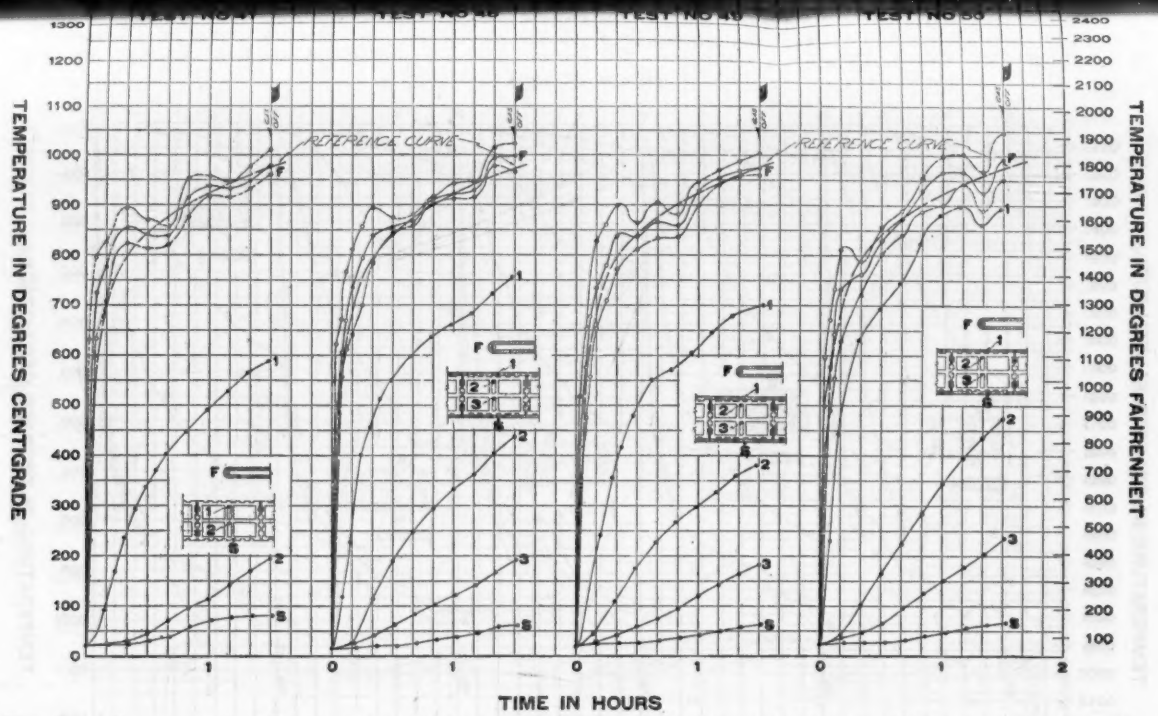


FIG. 88.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell "xxx" surface clay tile, source k, test No. 47; 8-inch wall of end construction 6-cell "xxx" surface clay tile, source k, cement plaster both sides, test No. 48; 8-inch wall of end construction 6-cell "xxx" surface clay tile, source k, gypsum plaster both sides, test No. 49; 8-inch wall of end construction 6-cell "xxx" surface clay tile, source k, lime plaster both sides, test No. 50*

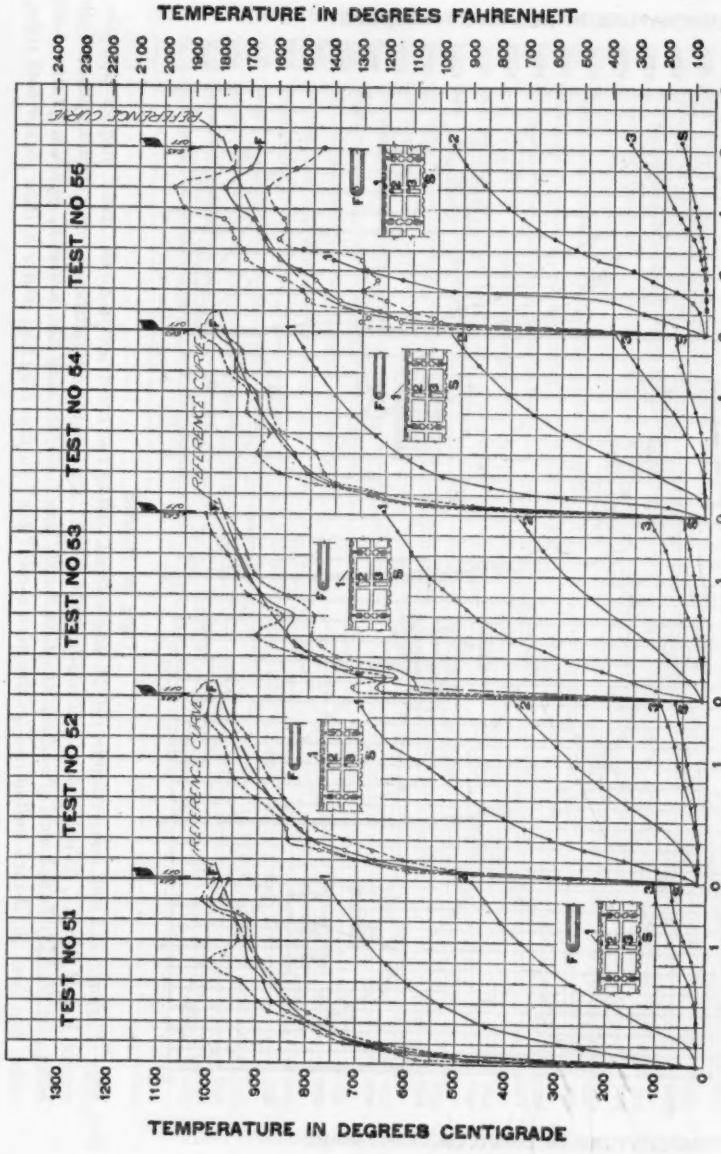


FIG. 89.—*Furnace and wall temperatures, 8-inch walls of end construction 6-cell "xxx" surface clay tile, source k, cement lime plaster fire side, tests Nos. 51, 52, and 53; 8-inch walls of end construction 6-cell "xxx" surface clay tile, source k, lime plaster fire side, tests Nos. 54 and 55*

FIG. 89.—*Furnace and wall temperatures, 8-inch walls of end construction 6-cell "xxx" surface clay cement lime plaster fire side, tests Nos. 51, 52, and 53; 8-inch walls of end construction 6-cell "xxx" surface clay tile, source k, lime plaster fire side, tests Nos. 54 and 55*

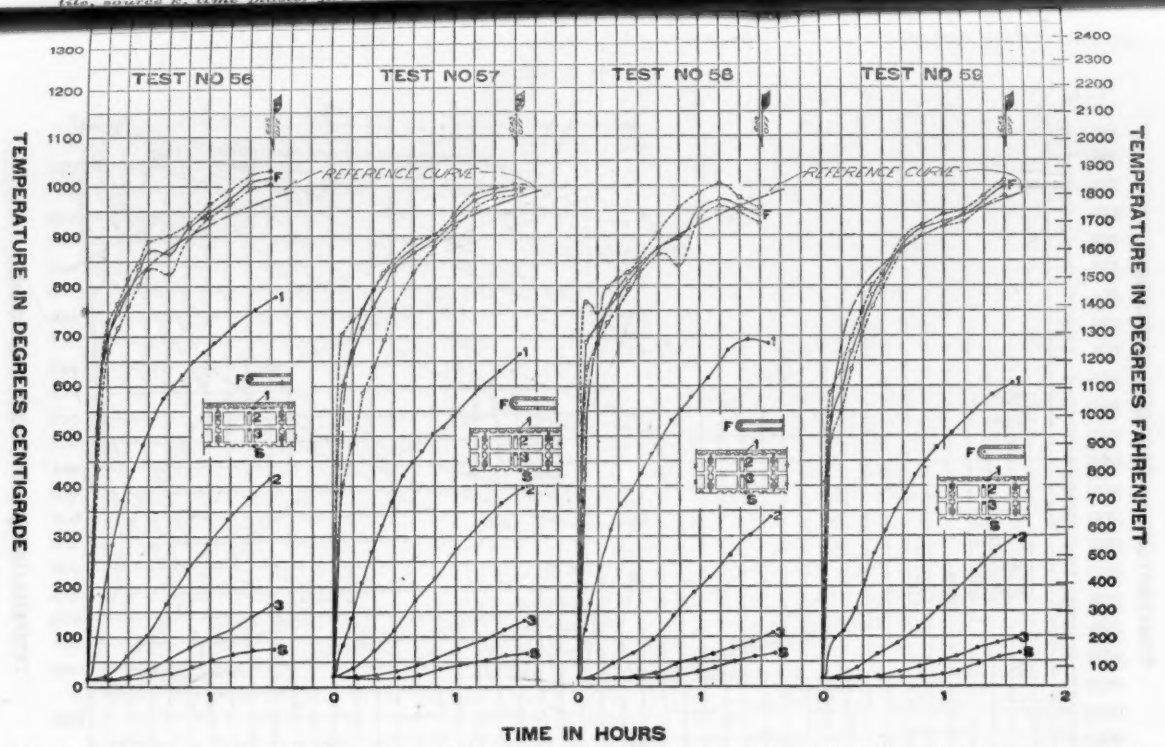


FIG. 90.—*Furnace and wall temperatures, 8-inch walls of end construction 6-cell "xxx" surface clay tile, source k, cement plaster fire side, tests Nos. 56 and 57; 8-inch walls of end construction 6-cell "xxx" surface clay tile, source k, gypsum plaster fire side, tests Nos. 58 and 59*

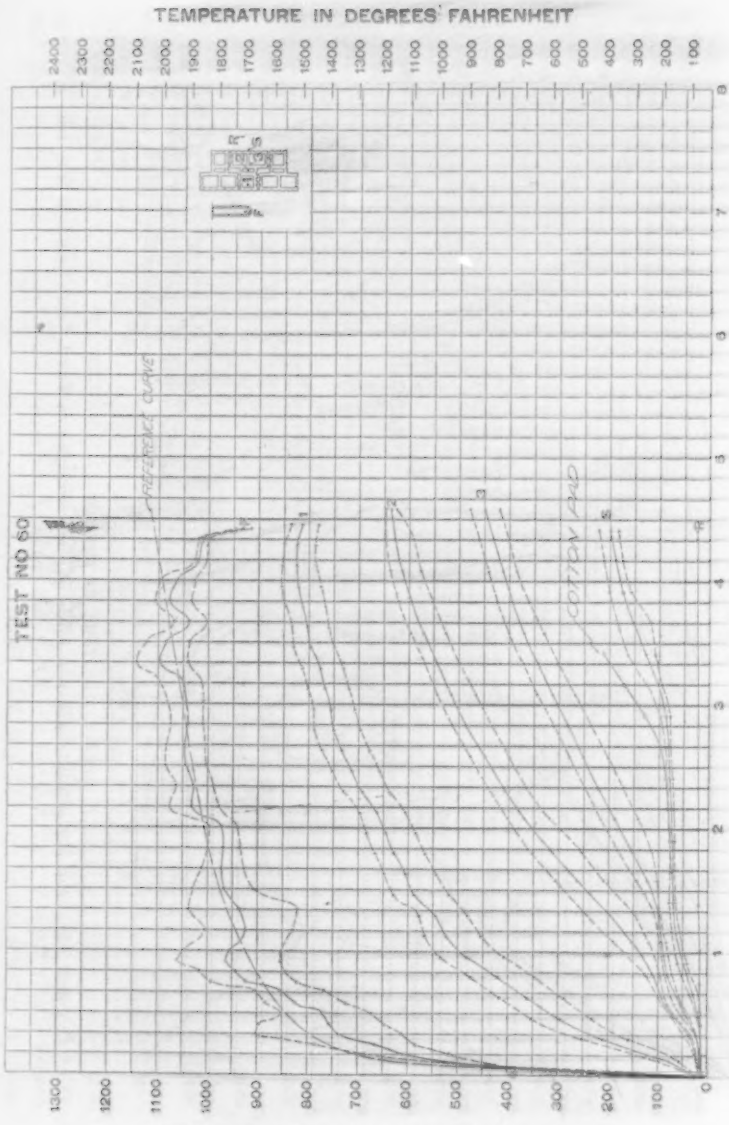


FIG. 51.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction interlocking surface clay tile, source 3—1, test No. 60.*

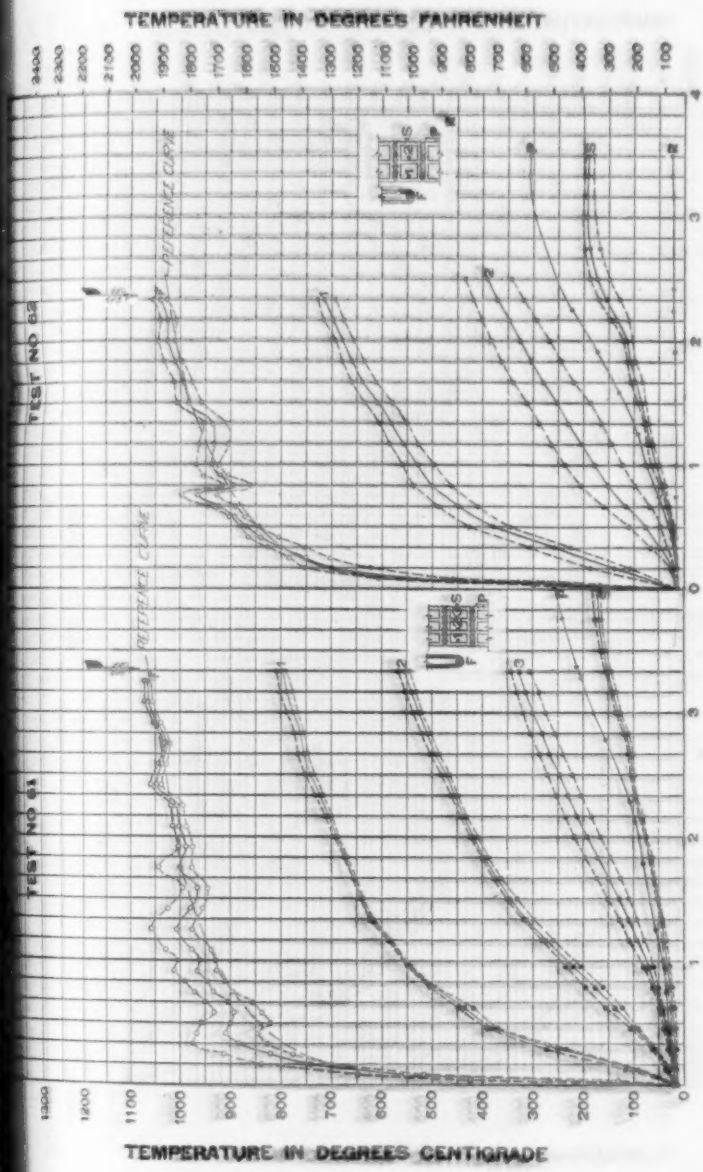


FIG. 92.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction 8 by 5 inch 3-cell surface clay tile, source o–1, test No. 61; 8-inch unplastered wall of side construction 8 by 5 inch 2-cell surface clay tile, source k–1, test No. 62*

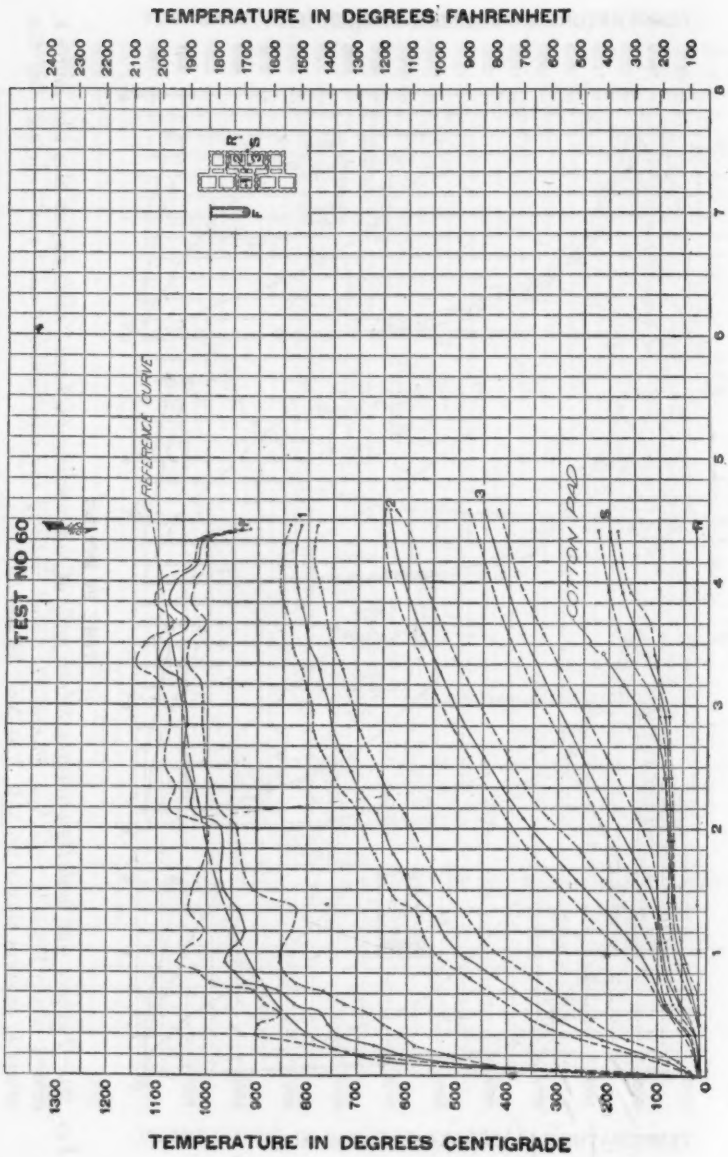


FIG. 91.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction interlocking surface clay tile, source p—1, test No. 60*

FIG. 91.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction interlocking [illegible] source p–1, test No. 60*

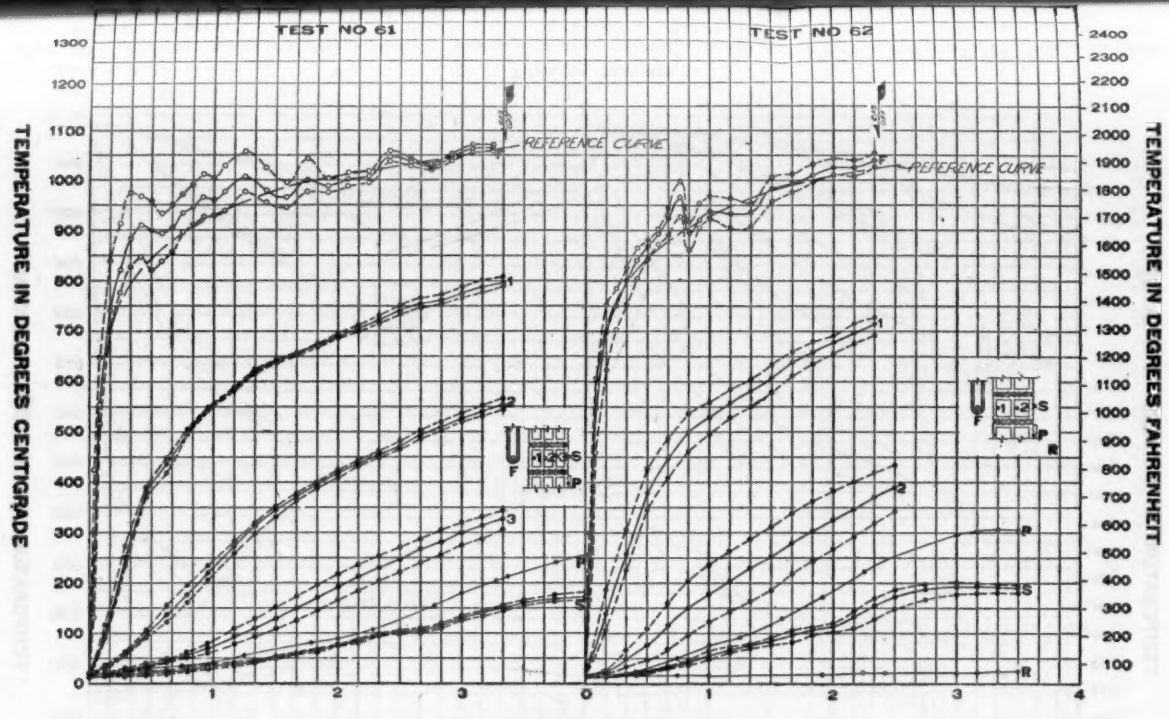


FIG. 92.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction 8 by 5 inch 3-cell surface clay tile, source o–1, test No. 61; 8-inch unplastered wall of side construction 8 by 5 inch 2-cell surface clay tile, source k–1, test No. 62*

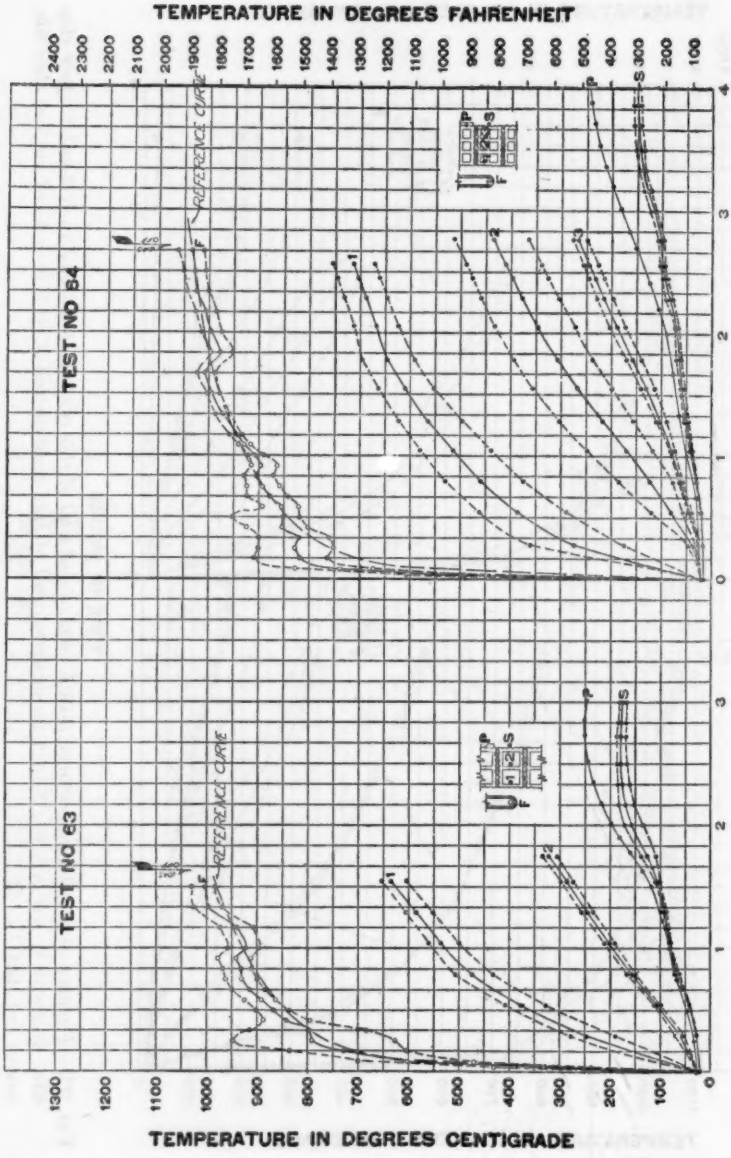


FIG. 93.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction 8 by 5 inch 2-cell surface clay tile, source K–S, test No. 63; 8-inch unplastered wall of side construction 8 by 5 inch 6-cell surface clay tile,*

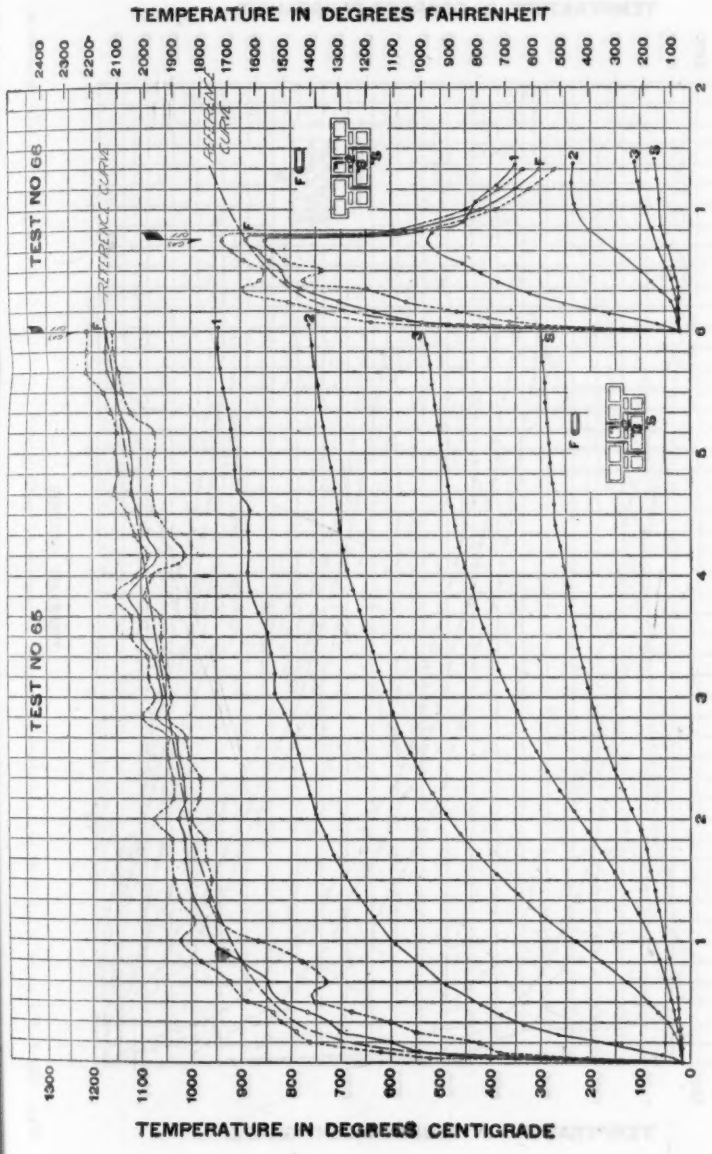


FIG. 94.—*Furnace and wall temperatures, 8-inch unplastered walls of side construction interlocking surface clay tile, source r, tests Nos. 65 and 66*

FIG. 93.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction interlocking surface clay tile, source K-3, test No. 63; 8-inch unplastered wall of side construction 8 by 5 inch 6-cell surface clay tile,*

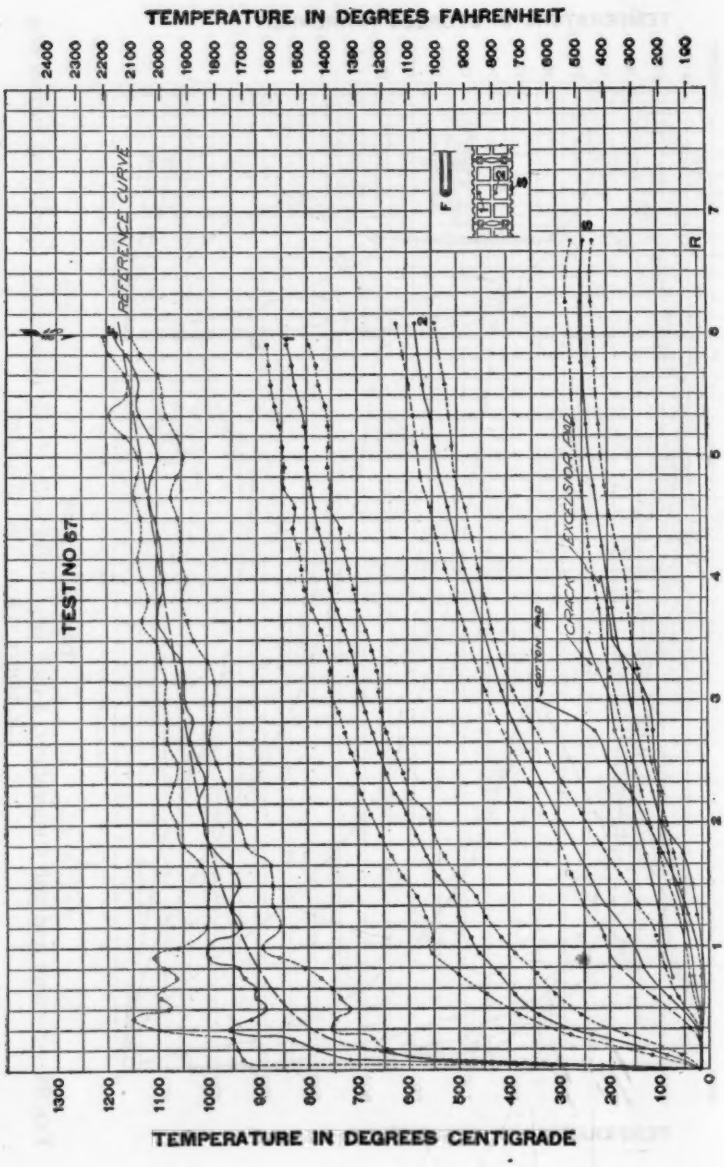


FIG. 95.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source n, test No. 67*

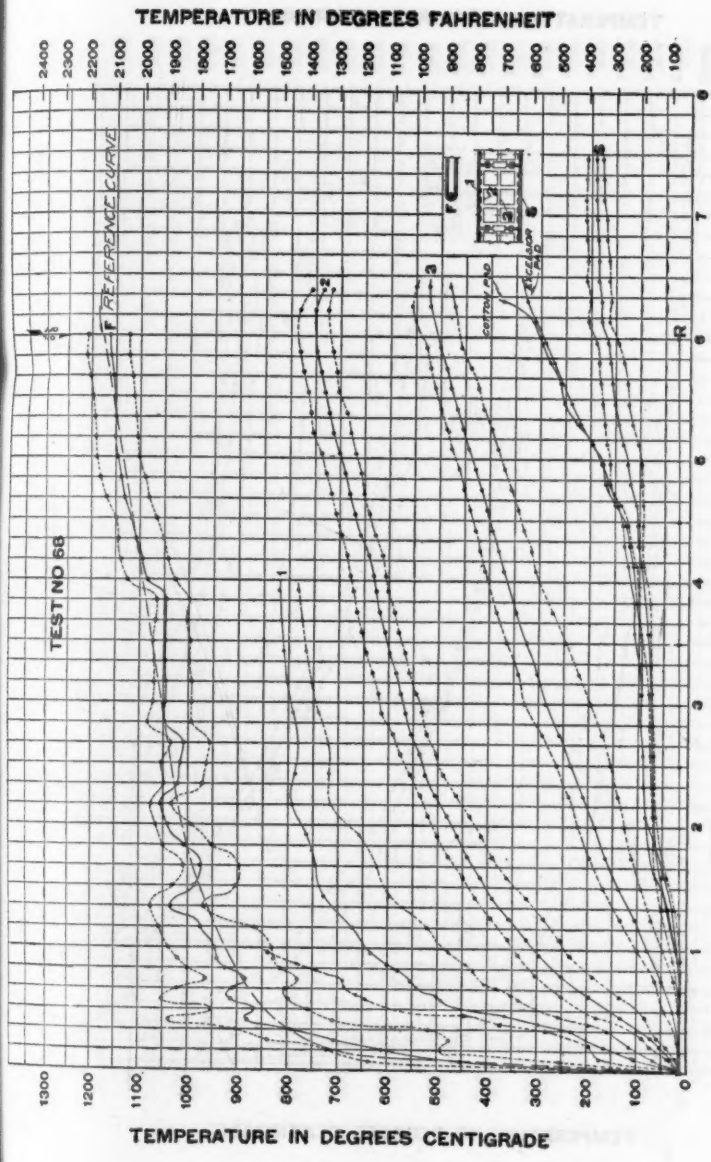


FIG. 96.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell fire clay tile, source n, gypsum plaster both sides, test No. 68*

FIG. 95.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source n, test No. 67*

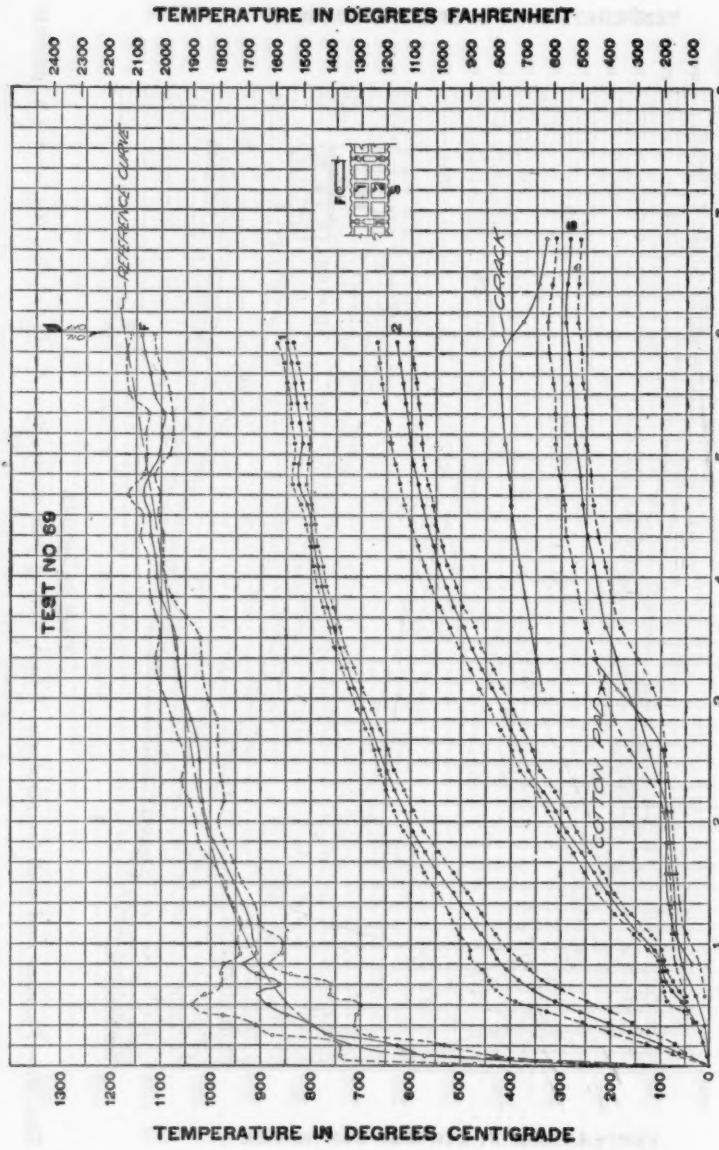


FIG. 97.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source n, test No. 69*

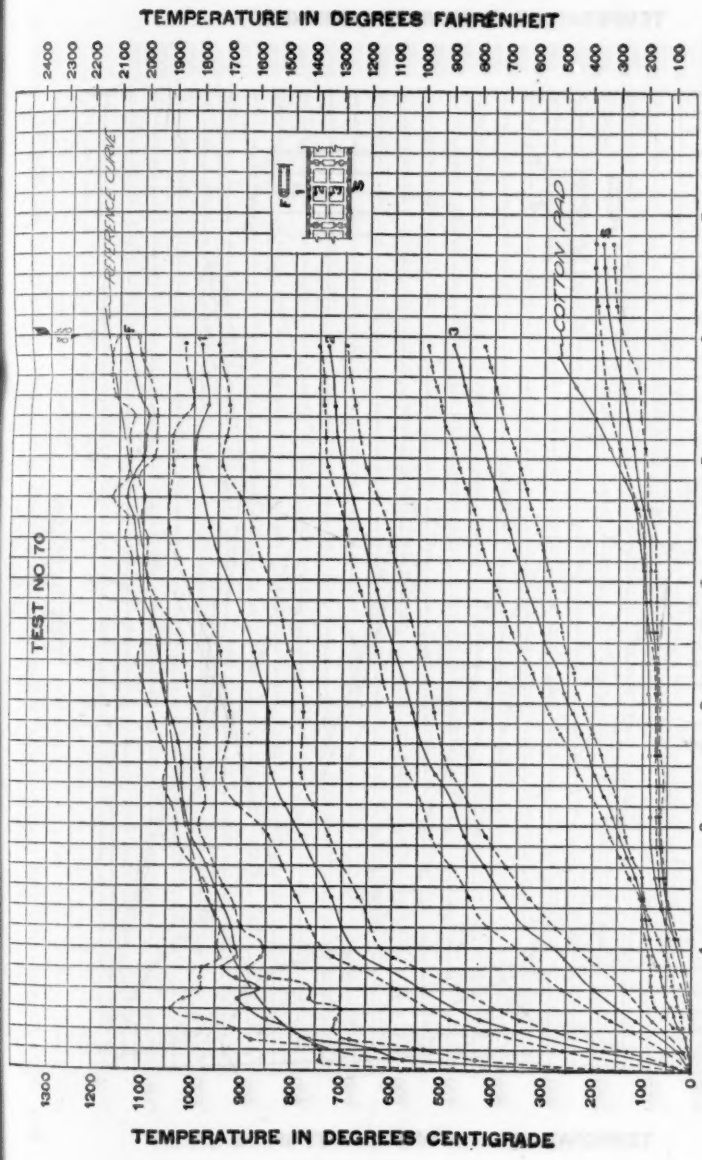


FIG. 98.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell fire clay tile, source n, gypsum plaster both sides, test No. 70*

FIG. 97.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source n, test No. 69*

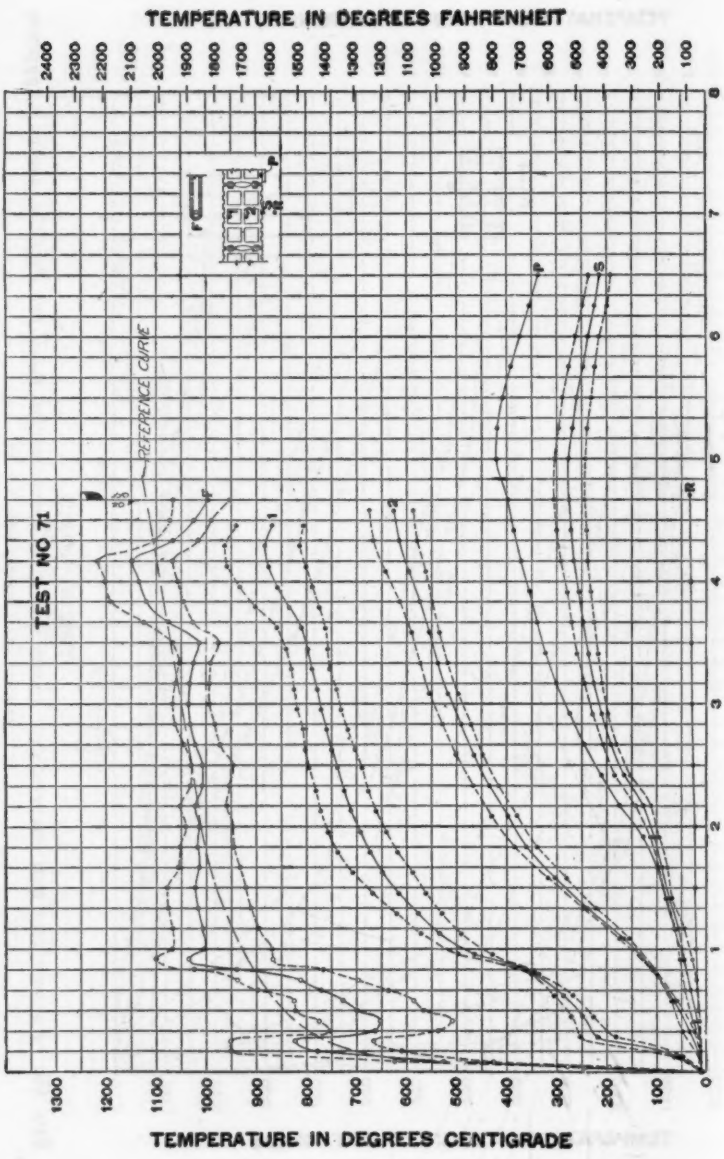


FIG. 99.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source n, test No. 71*

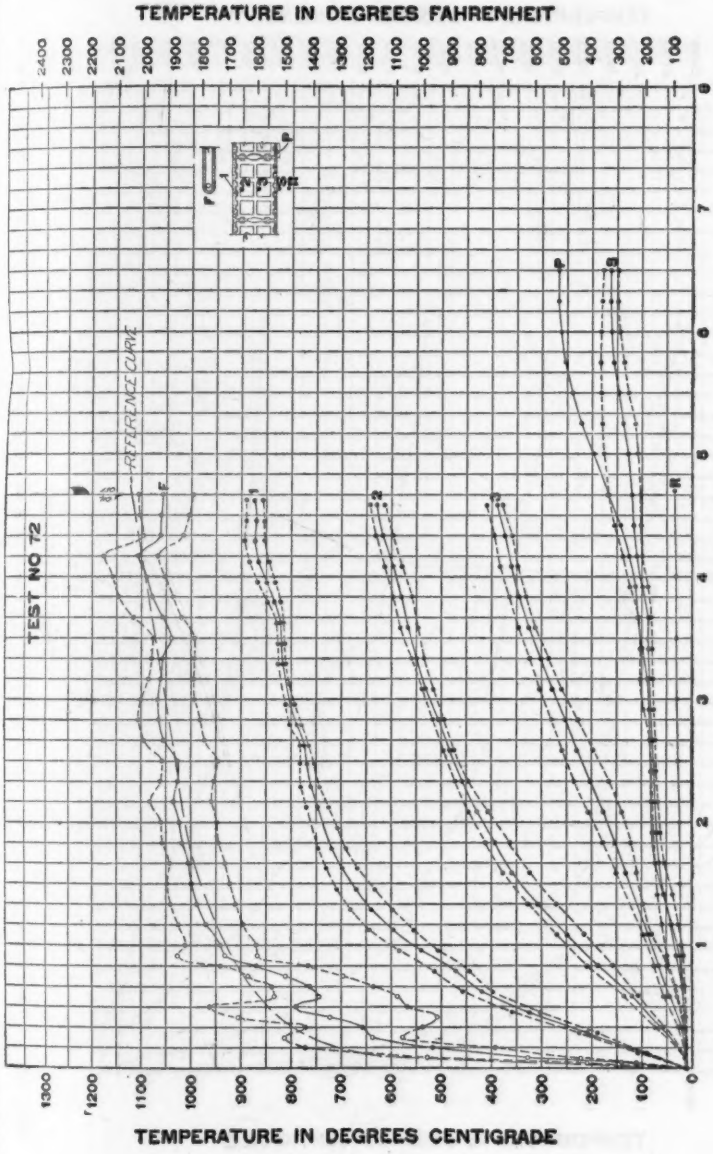


FIG. 100.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell fire clay tile, source n, gypsum plaster both sides, test No. 72*

FIG. 99.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source n, test No. 71*

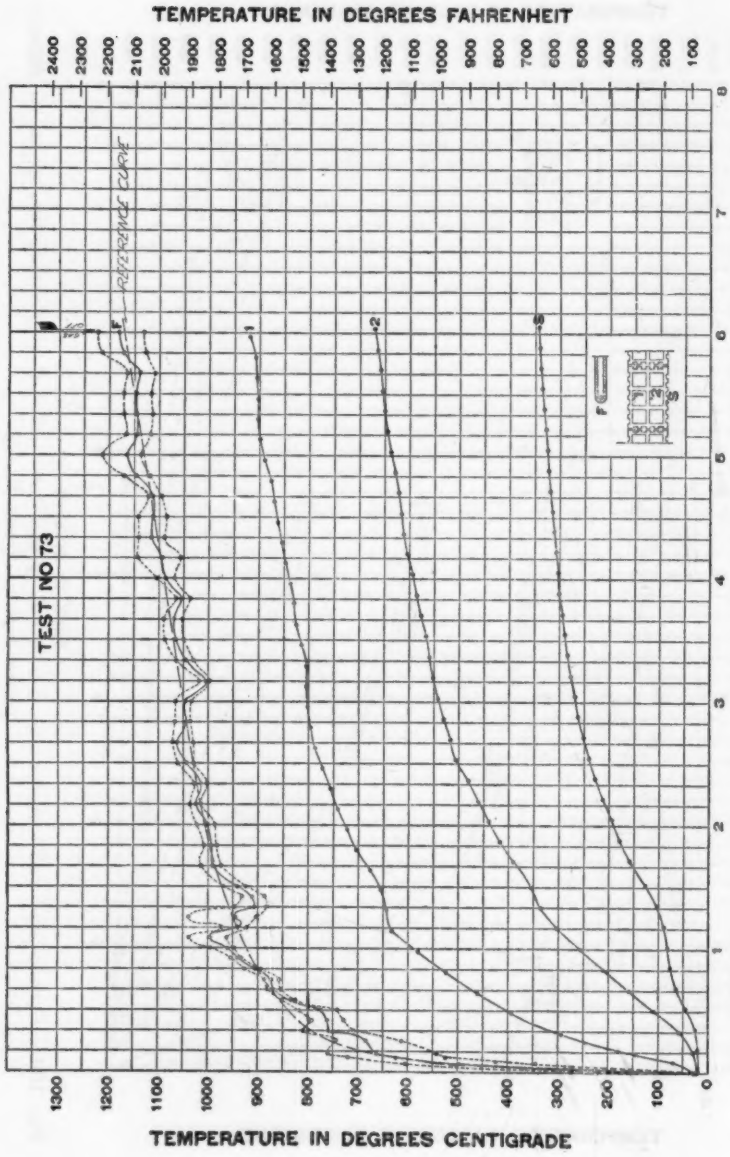


FIG. 101.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source 1, test No. 73*

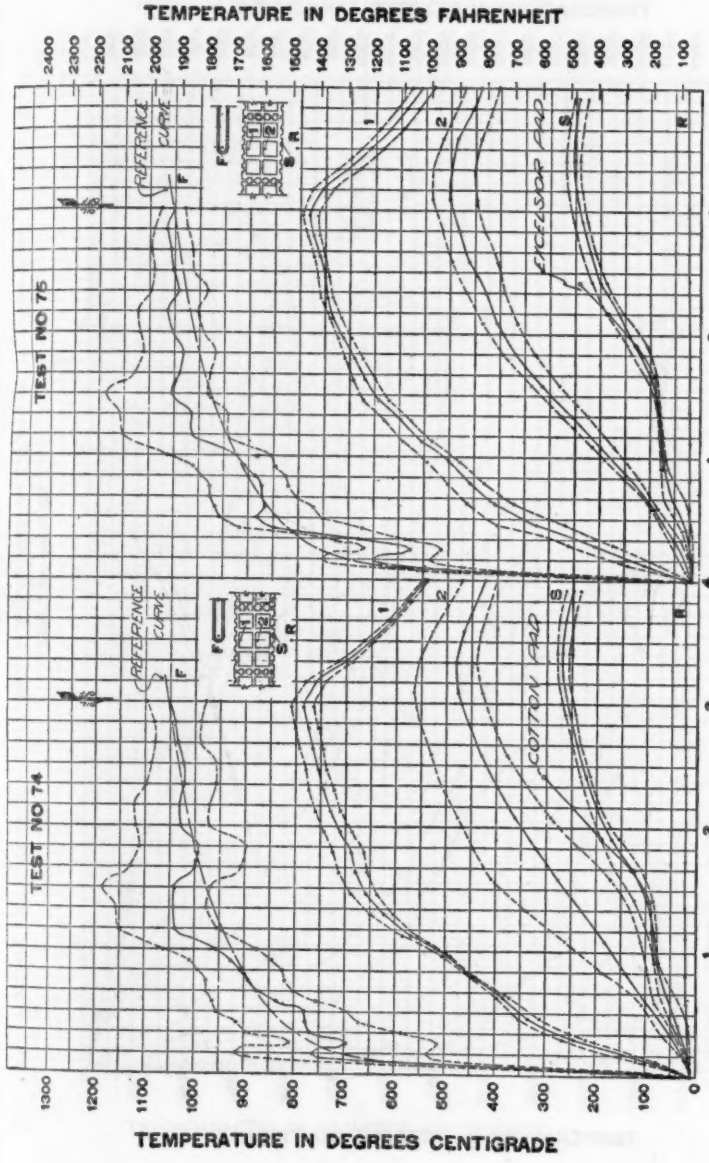


FIG. 102.—*Furnace and wall temperatures, 8-inch unplastered walls of end construction 6-cell fire clay tile, source l, tests Nos. 74 and 75*

FIG. 101.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source l, test No. 73*

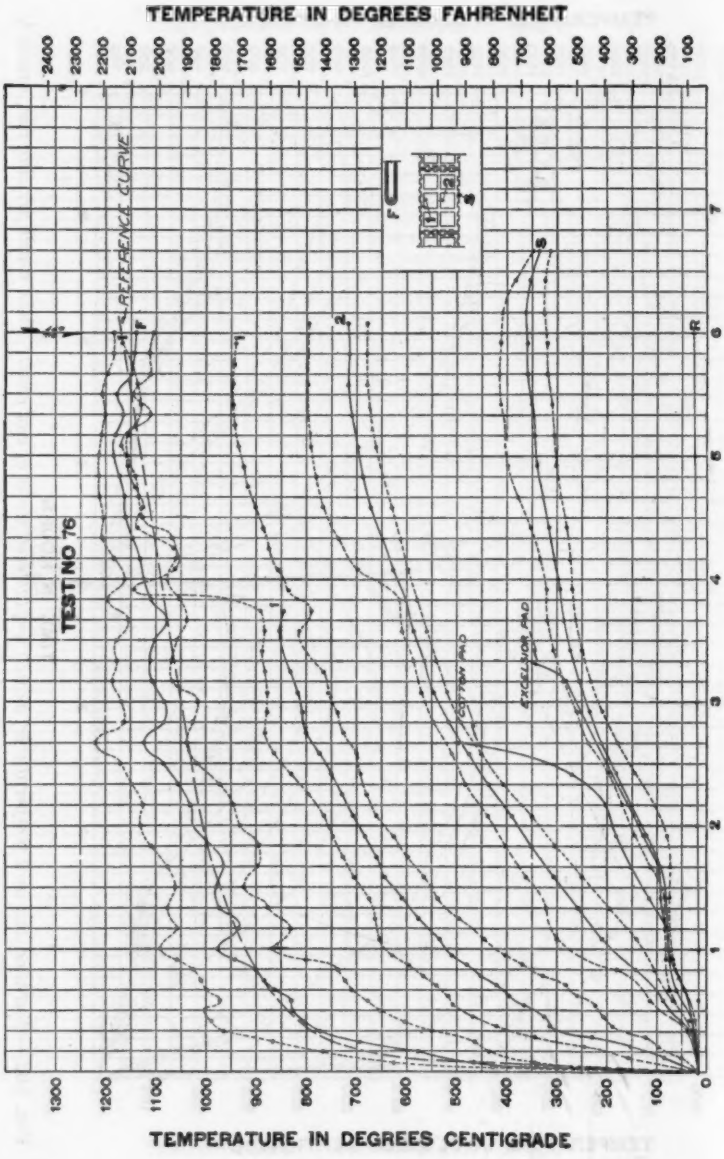


FIG. 103.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source 1, test No. 76*

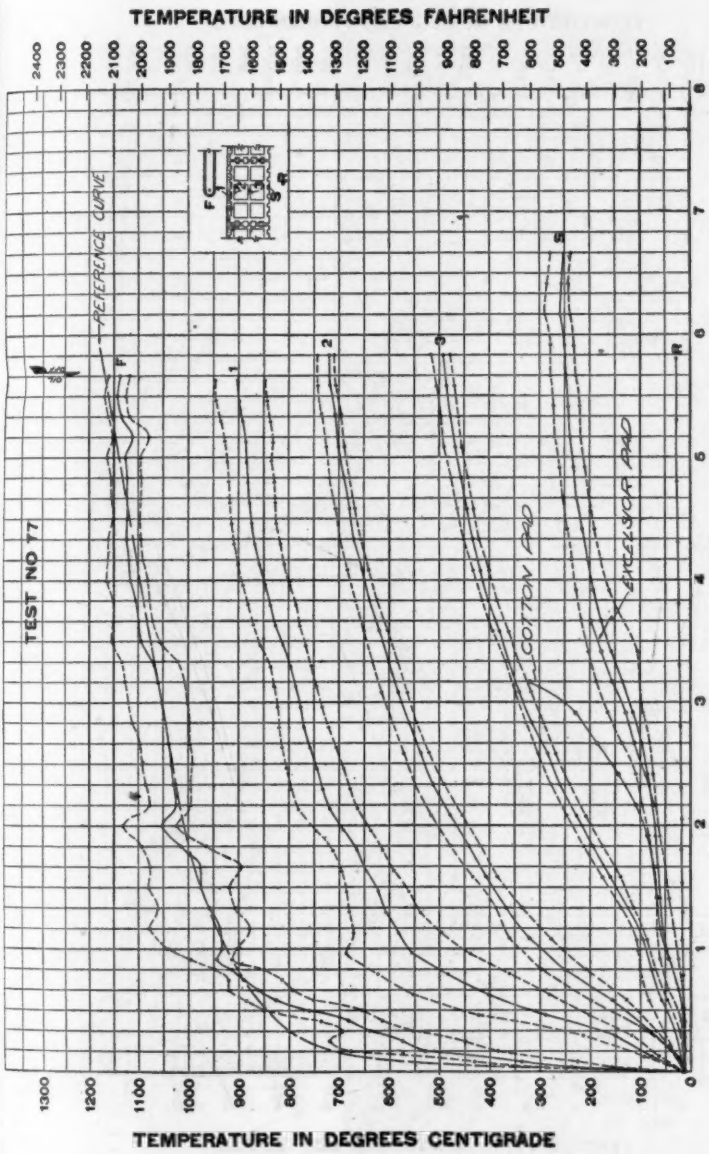


FIG. 104.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell fire clay tile, source, source l, gypsum plaster fire side, test No. 77*

FIG. 103.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source t, test No. 76*

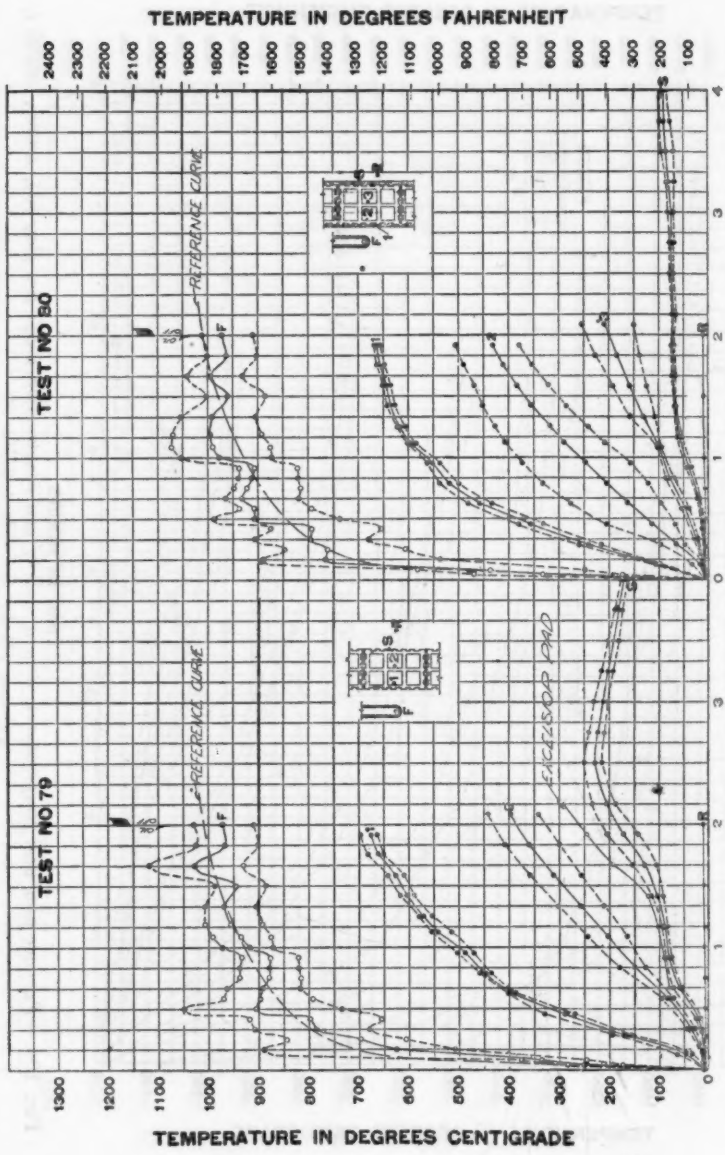


FIG. 105.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source 1, set on side, test No. 79; 8-inch wall of end construction 6-cell fire clay tile, source 1, set on side, gypsum plaster both sides, test No. 80.*

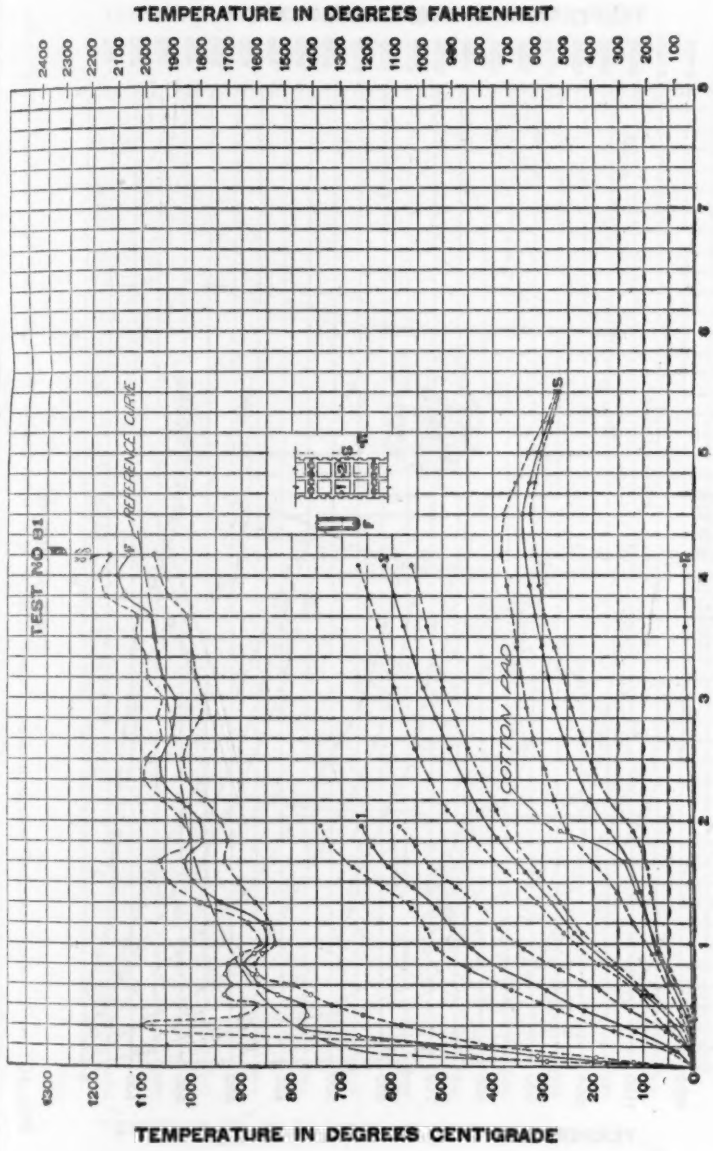


FIG. 106.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source l, set on side, test No. 81*

FIG. 105.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source l, set on side, test No. 79; 8-inch wall of end construction 6-cell fire clay tile, source L, set on side, gypsum plaster both sides, test No. 80.*

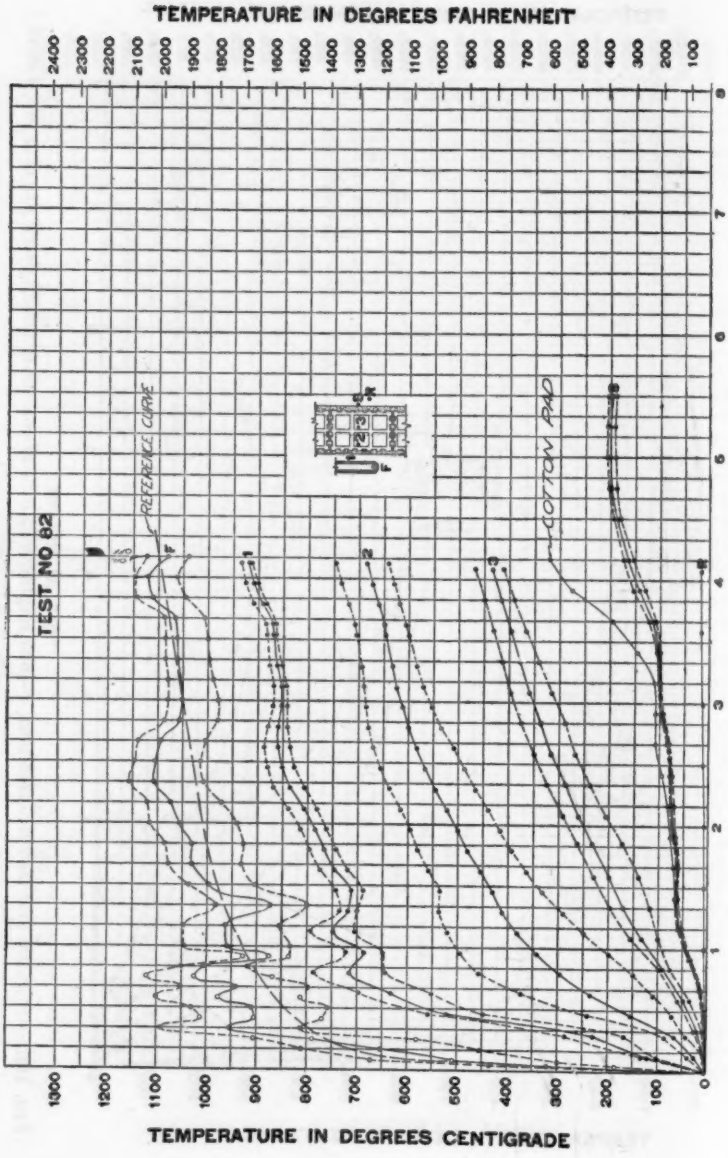


FIG. 107.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell fire clay tile, source 1, set on side, gypsum plaster both sides, test No. 82*

TIME IN HOURS

FIG. 107.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell fire clay tile, source l, set on side, gypsum plaster both sides, test No. 82*

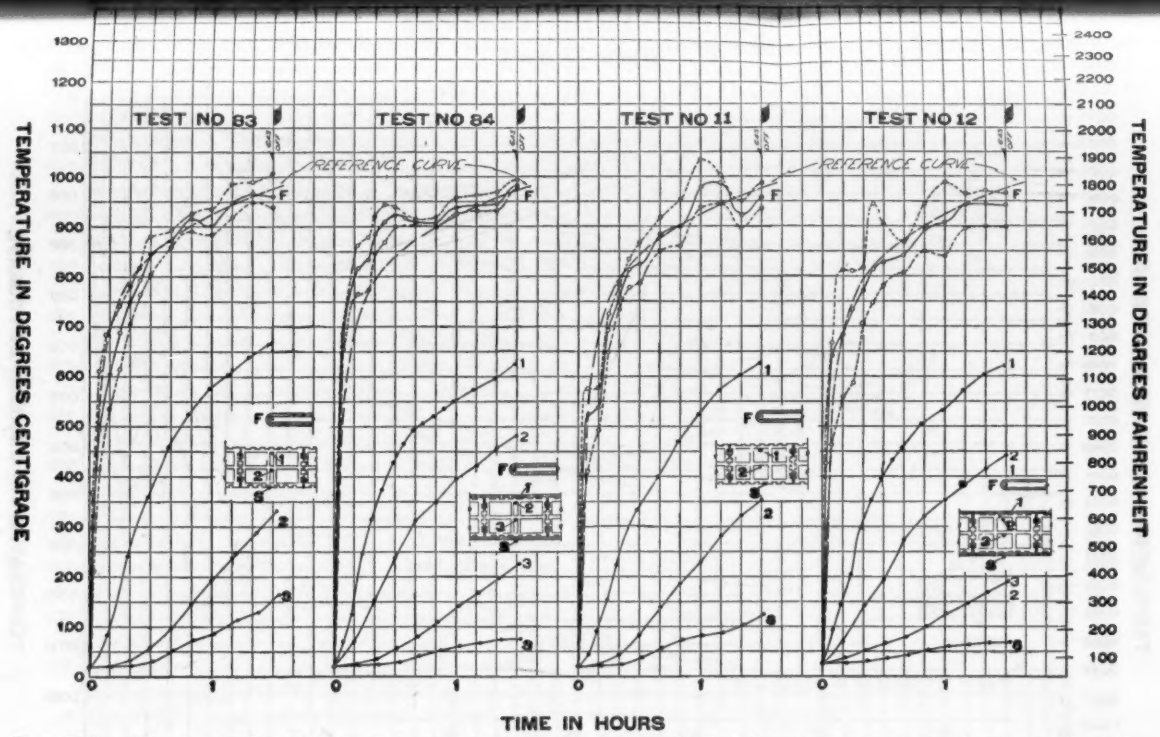


FIG. 108.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell "xxx" fire clay tile, source m, test No. 83; 8-inch wall of end construction 6-cell "xxx" fire clay tile, source m, gypsum plaster both sides, test No. 84; 8-inch unplastered wall of end construction 6-cell shale tile, source d, test No. 11; 8-inch wall of end construction 6-cell shale tile, source d, gypsum plaster both sides, test No. 12*

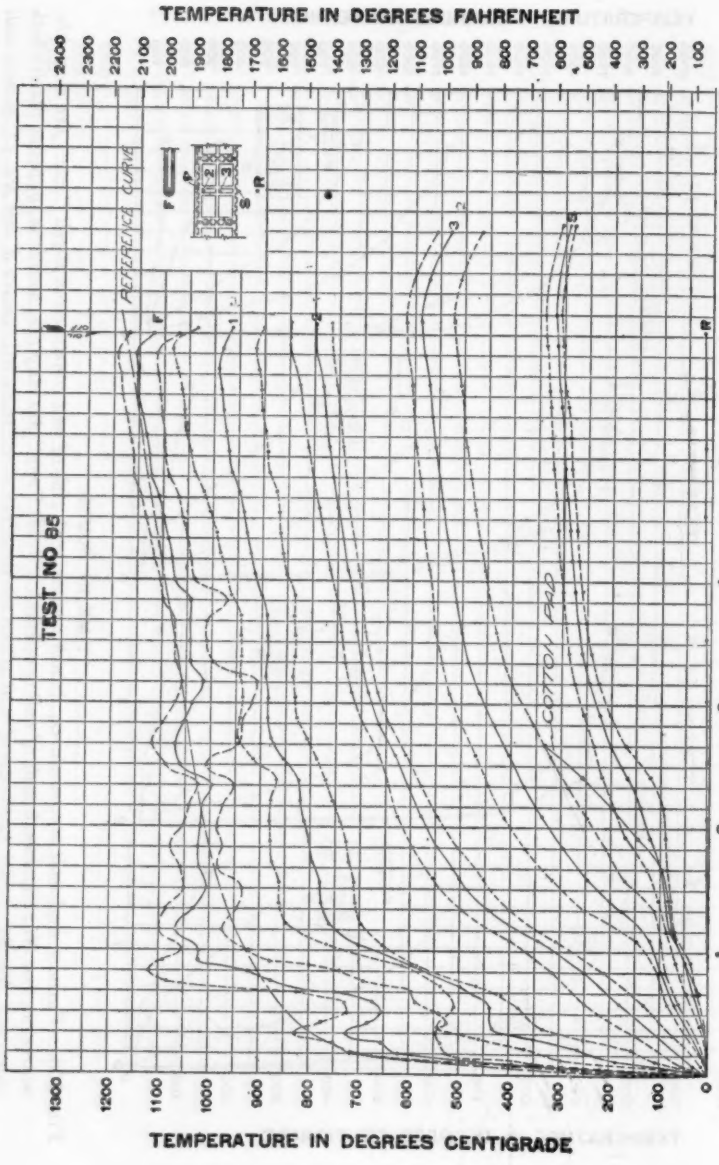


FIG. 109.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell "xxx" fire clay tile, source m, cement plaster fire side, test No. 85*

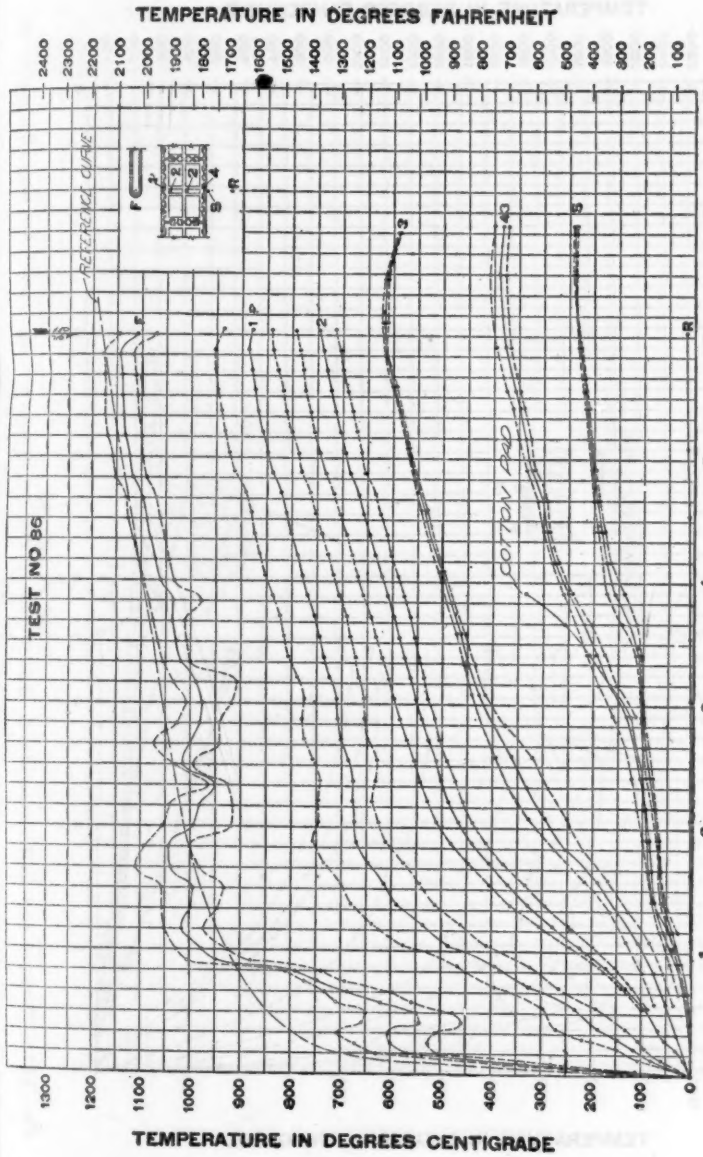


FIG. 110.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell "xxx" fire clay tile, source m, gypsum plaster both sides, test No. 86*

FIG. 109.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell "xxx" fire clay tile, source m, cement plaster fire side, test No. 86*

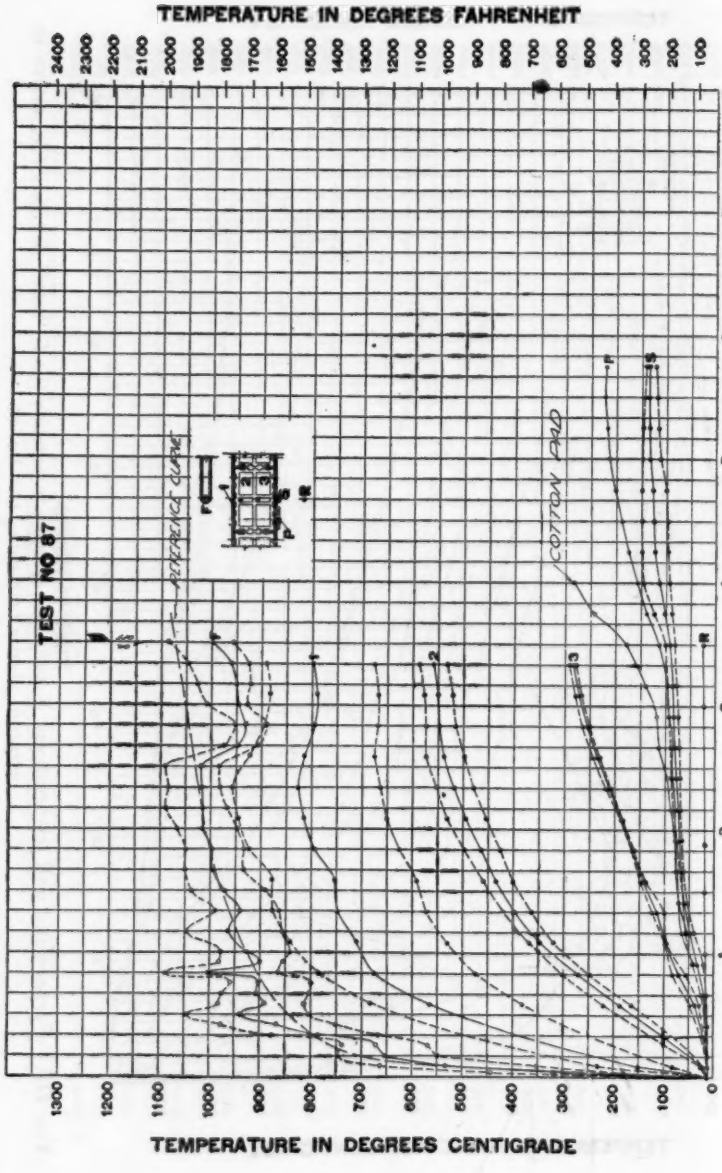


FIG. 111.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell "xx" fire clay tile, source m, gypsum plaster both sides, test No. 87*

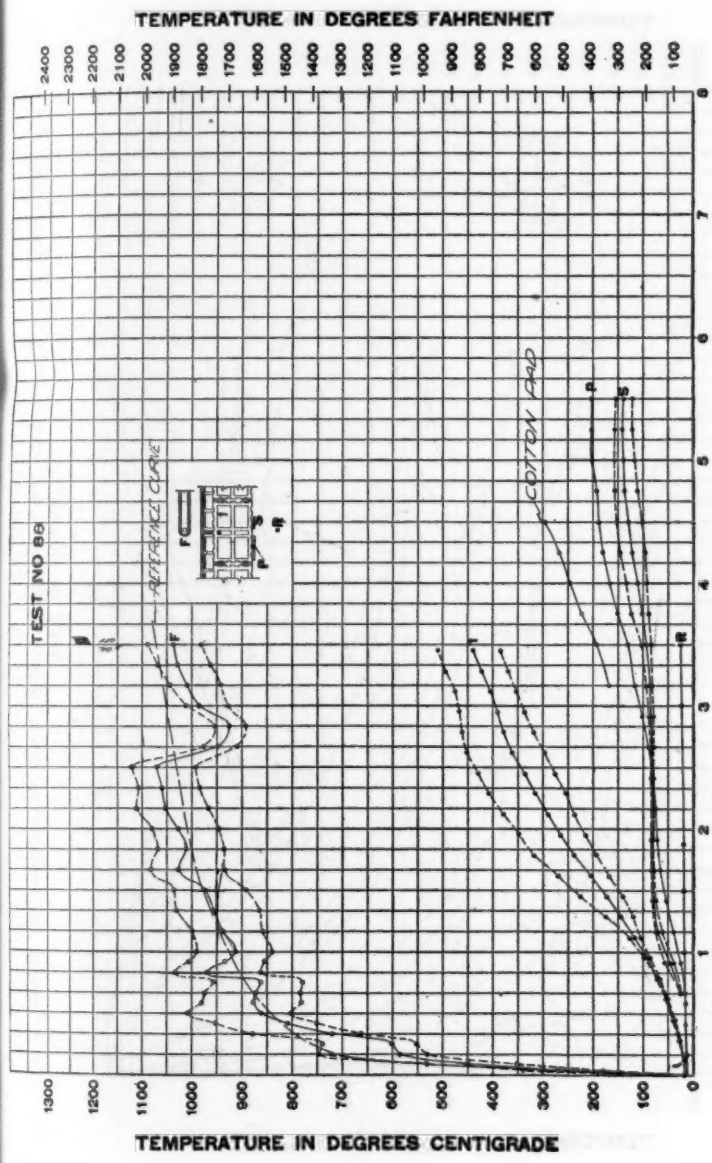


FIG. 112.—*Furnace and wall temperatures, 8-inch wall furred on fire side of end construction 6-cell "xxx" fire clay tile, source m, gypsum plaster fire side, test No. 88*

FIG. 111.—*Furnace and wall temperatures, 8-inch wall of end construction 6-cell "xxx" fire clay tile, source m, gypsum plaster both sides, test No. 87*

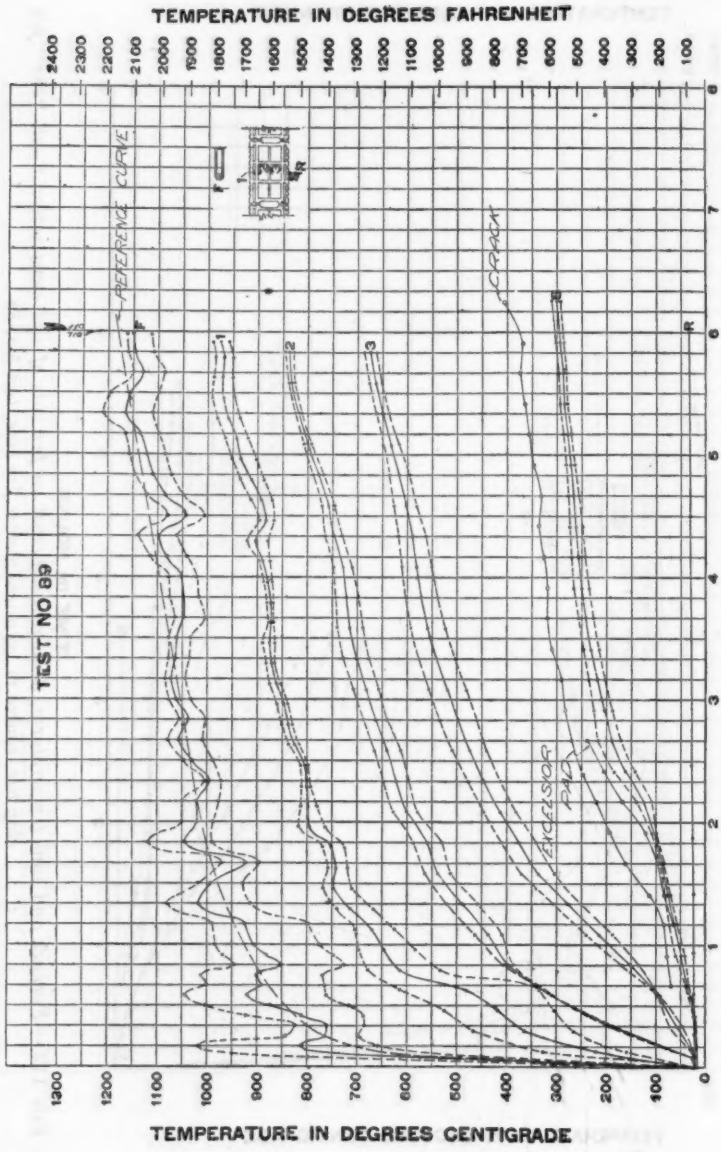


FIG. 113.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction double shell fire clay tile, source m, test No. 89*

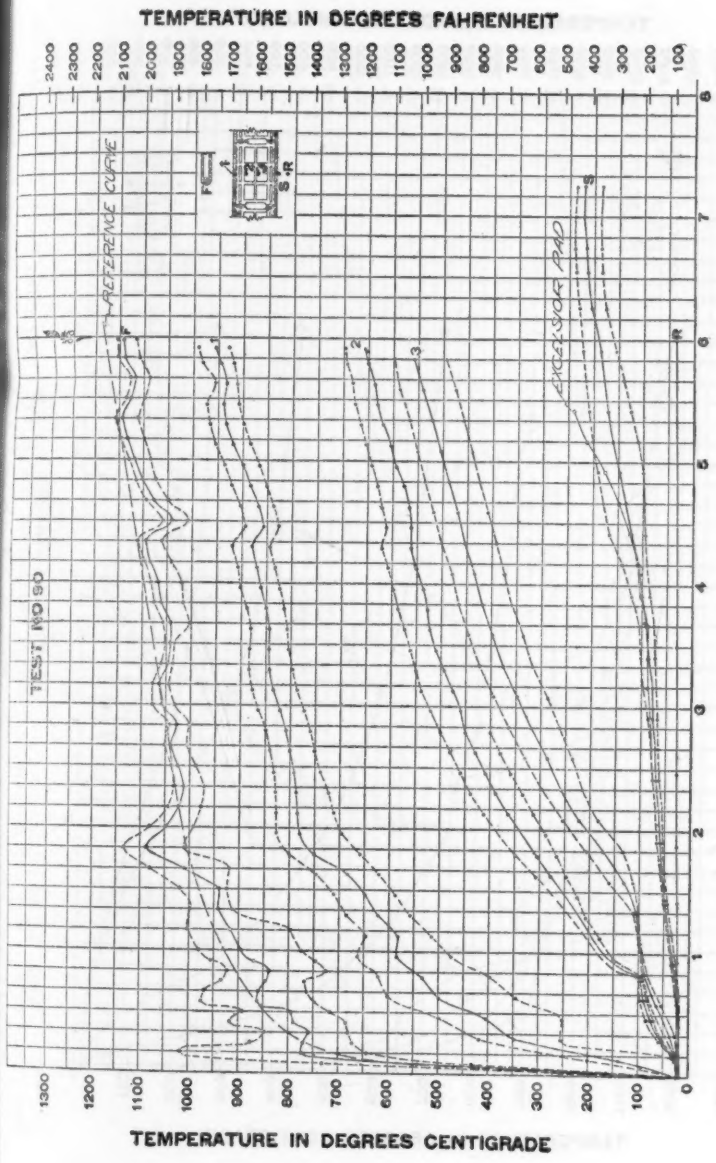


FIG. 114.—*Furnace and wall temperatures, 8-inch wall of end construction double shell fire clay tile, source m, gypsum plaster both sides, test No. 90*

FIG. 113.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction double shell fire clay tile, source m, test No. 89*

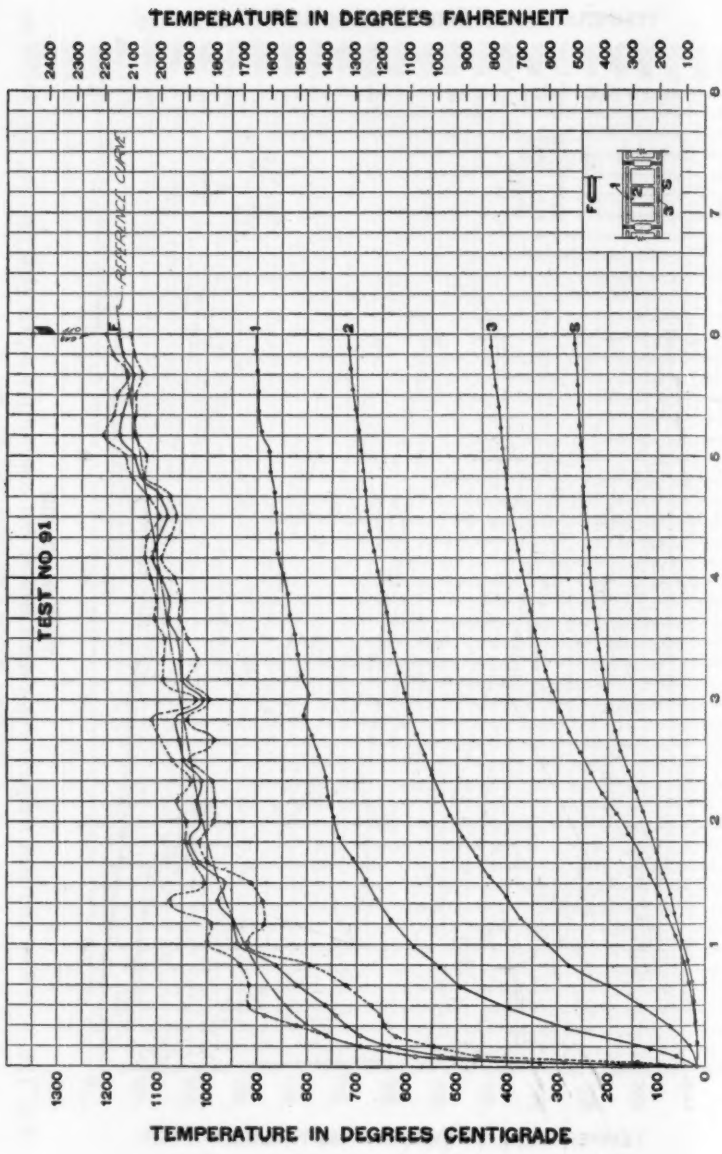


FIG. 115.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction double shell fire clay tile, source m, test No. 91*

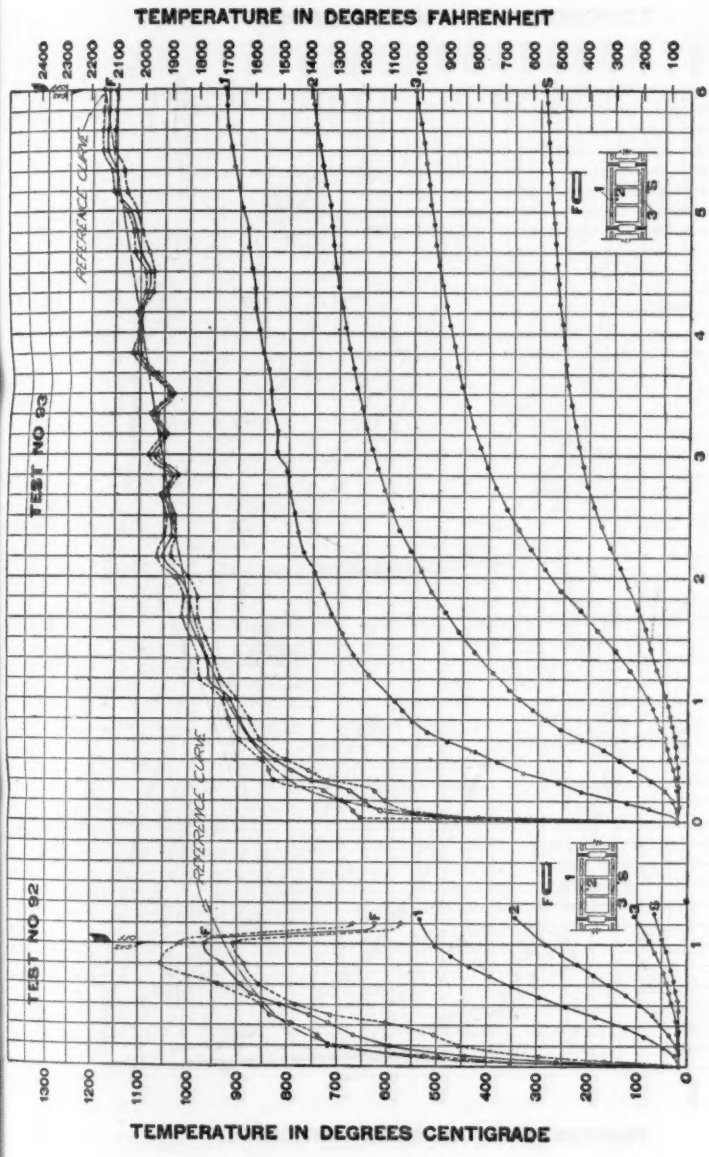


Fig. 116.—*Furnace and wall temperatures, 8-inch unplastered walls of end construction double shell fire clay tile, source m, tests Nos. 92 and 93*

Fig. 115.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction double shell fire clay tile, source m, test No. 91*

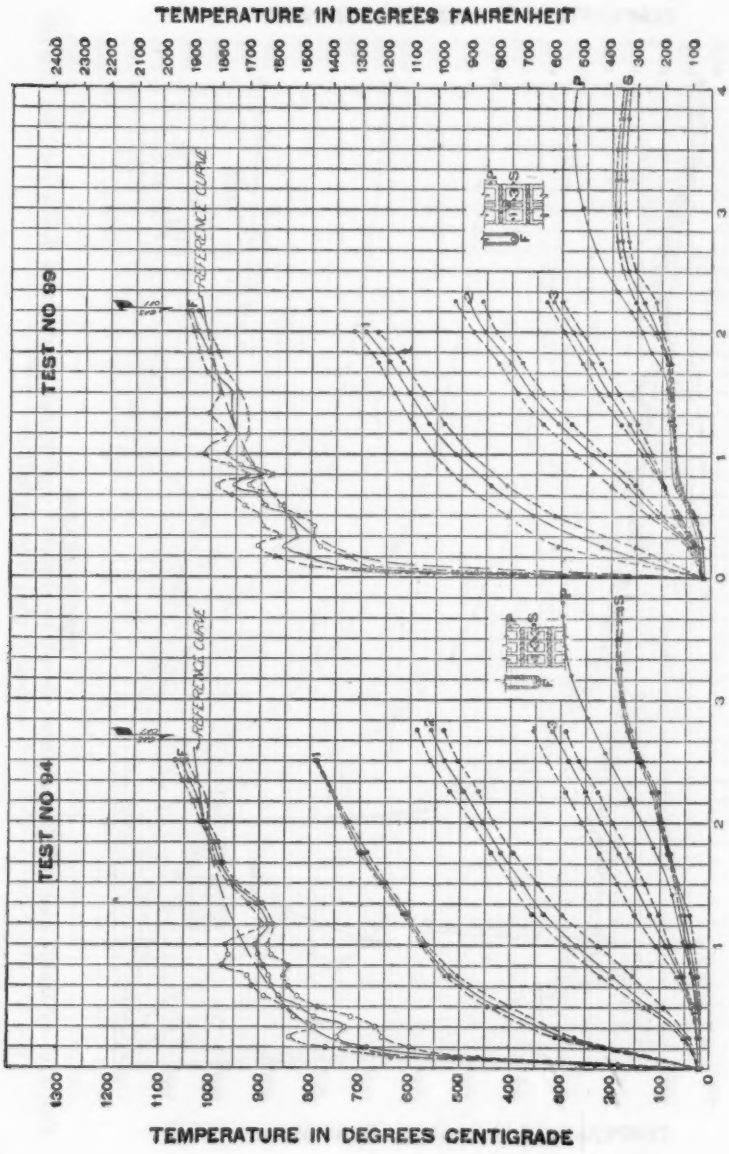


FIG. 117.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction 8 by 5 inch 3-cell fire clay tile, source h, test No. 94; 8-inch unplastered wall of side construction 8 by 5 inch 3-cell fire clay tile, source l–2, test No. 99*

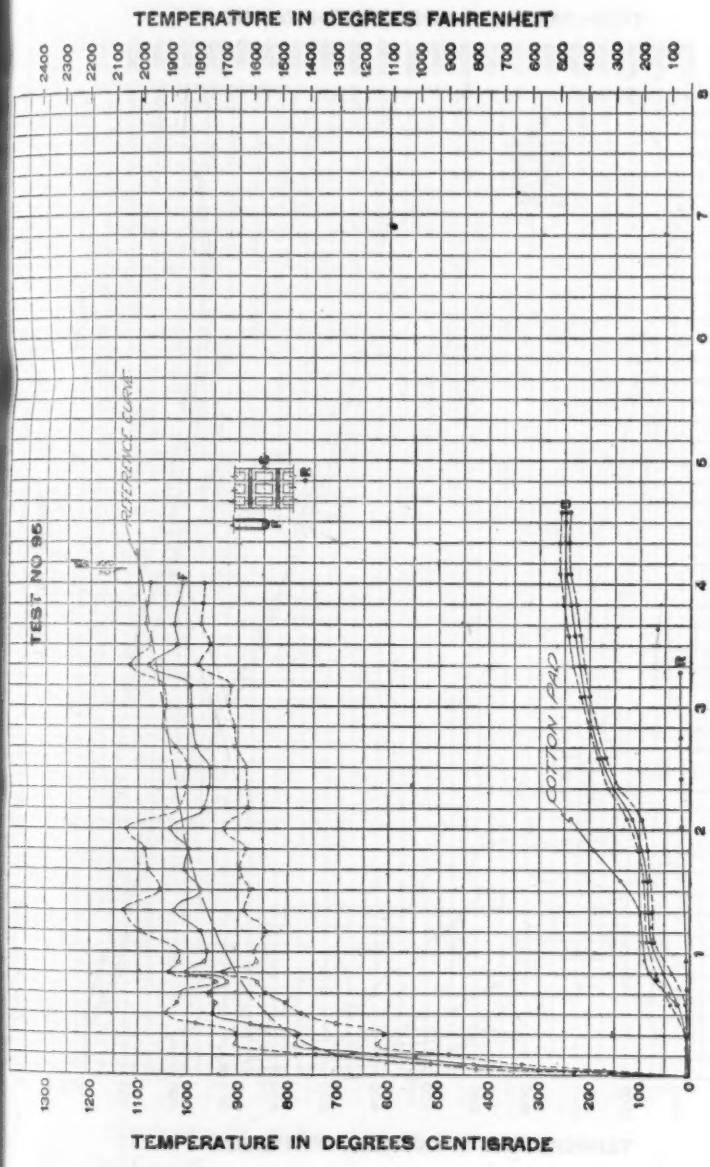


FIG. 118.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction 8 by 5 inch 3-cell fire clay tile, source m, test No. 95*

FIG. 117.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction 8 by 5 inch 3-cell fire clay tile, source h, test No. 94; 8-inch unplastered wall of side construction 8 by 6 inch 3-cell fire clay tile, source l-2, test No. 92*

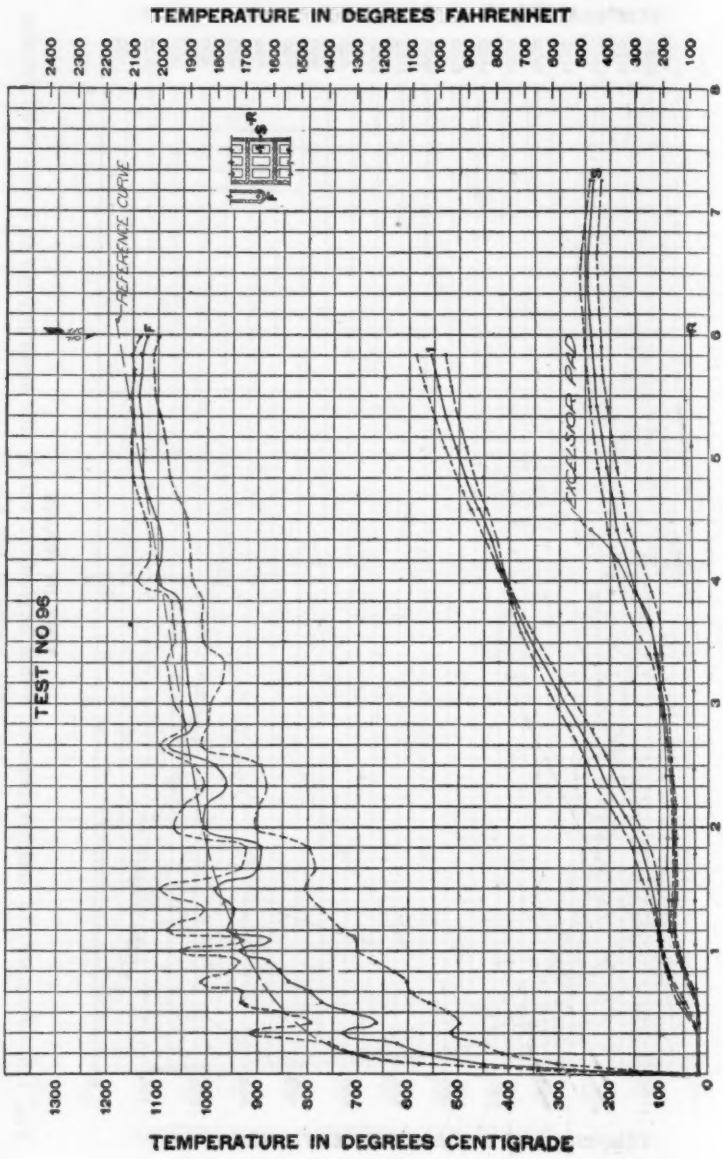


FIG. 119.—*Furnace and wall temperatures, 8-inch wall of side construction 8 by 5 inch 3-cell fire clay tile, source m, gypsum plaster both sides, test No. 96*

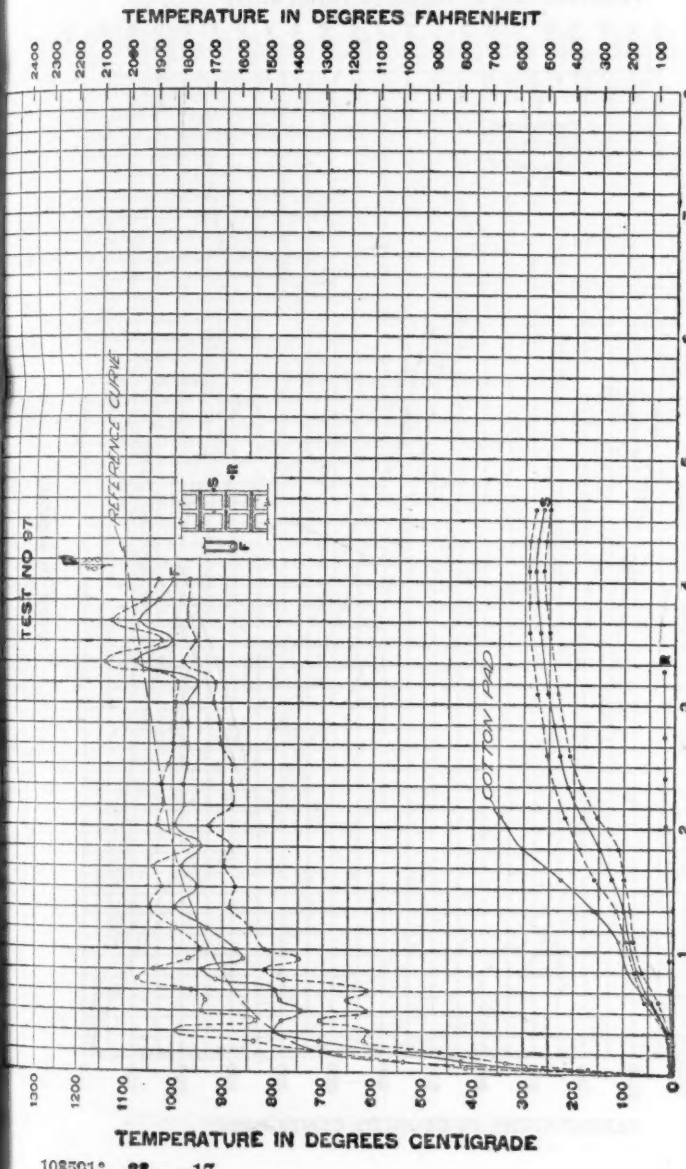


FIG. 120.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction 8 by 5 inch 2-cell fire clay tile, source m, test No. 97*

FIG. 119.—*Furnace and wall temperatures, 8-inch wall of side construction 8 by 5 inch 3-cell fire clay tile, source m, gypsum plaster both sides, test No. 23*

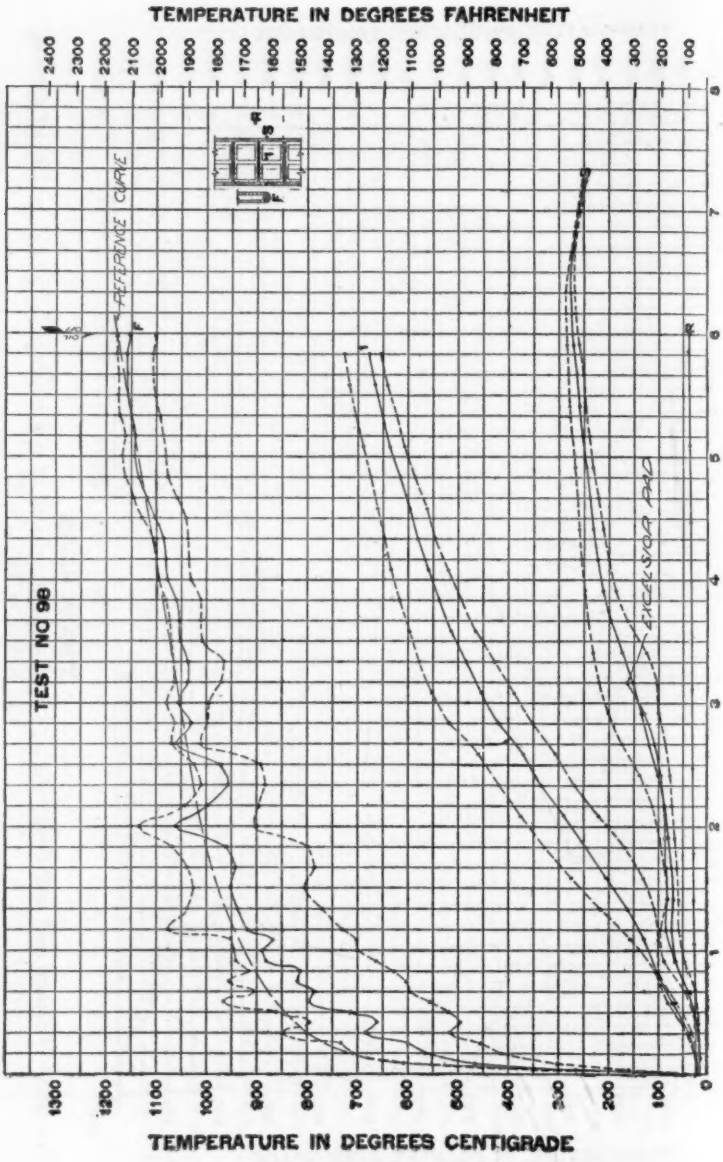


Fig. 121.—*Furnace and wall temperatures, 8-inch wall of side construction 8 by 5 inch 2-cell fire clay tile, source m, gypsum plaster both sides, test No. 98*

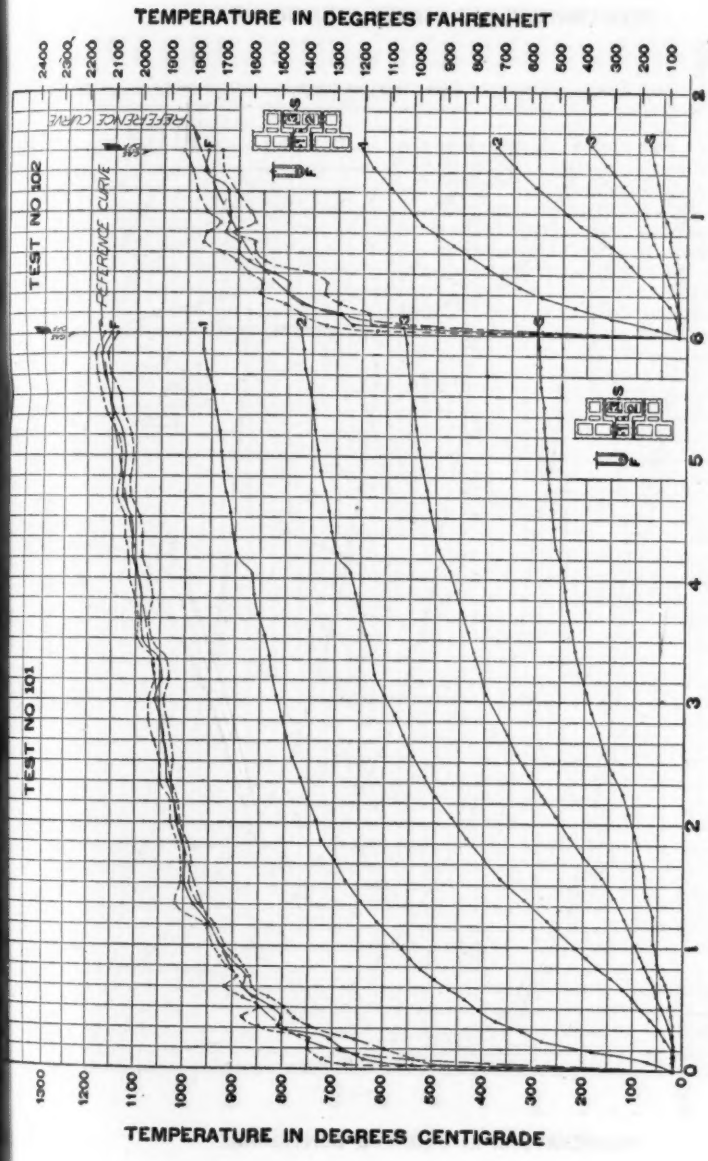


FIG. 121.—*Furnace and wall temperatures, 8-inch wall of side construction 8 by 5 inch 2-cell fire clay tile, source m, unplastered, both sides, test Nos. 93*

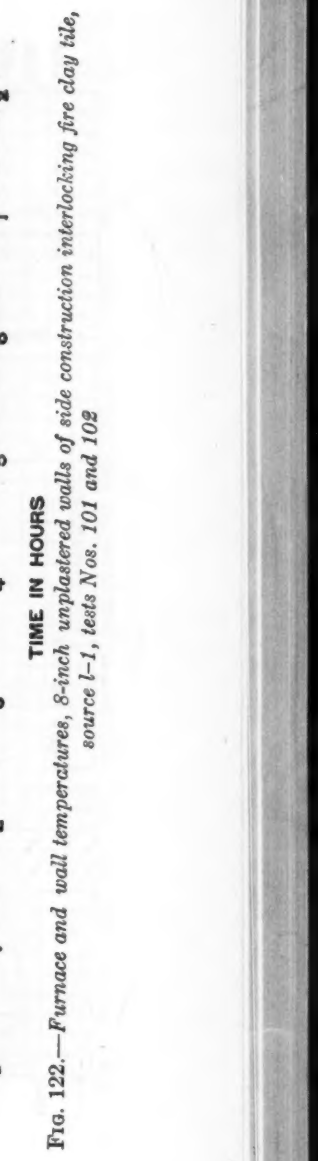


FIG. 122.—*Furnace and wall temperatures, 8-inch unplastered walls of side construction interlocking fire clay tile, source l–1, tests Nos. 101 and 102*

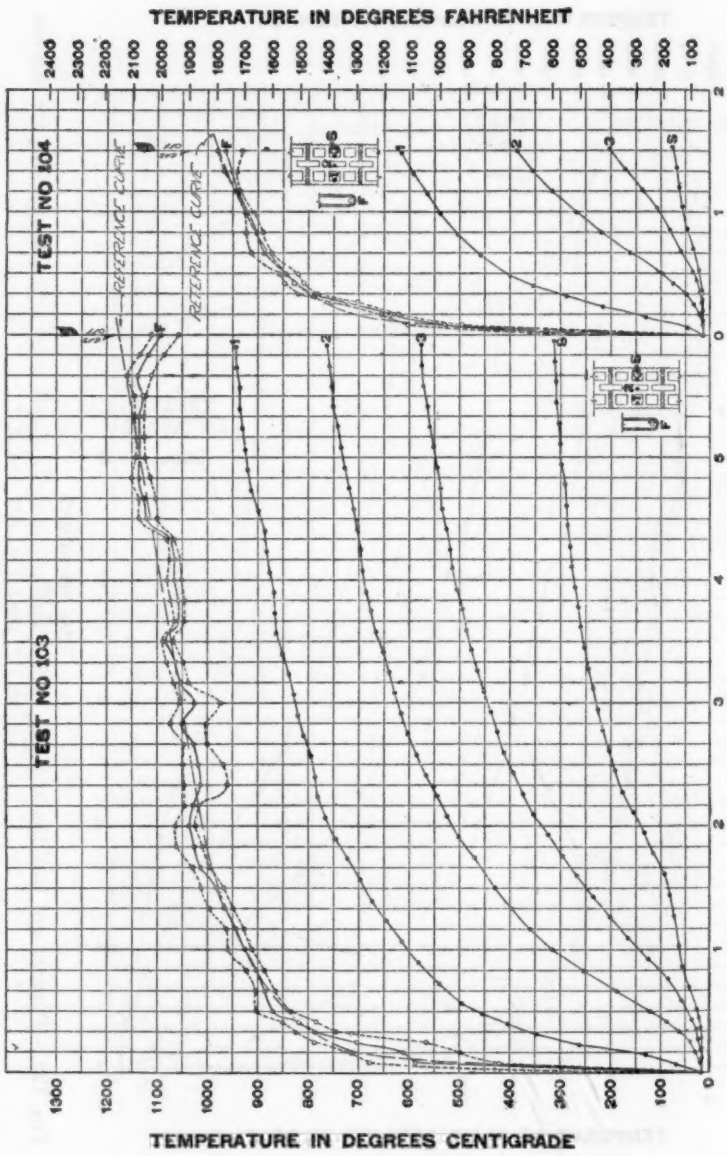


FIG. 123.—*Furnace and wall temperatures, 8-inch unplastered walls of side construction H-shaped fire clay tile, source 1, tests Nos. 103 and 104*

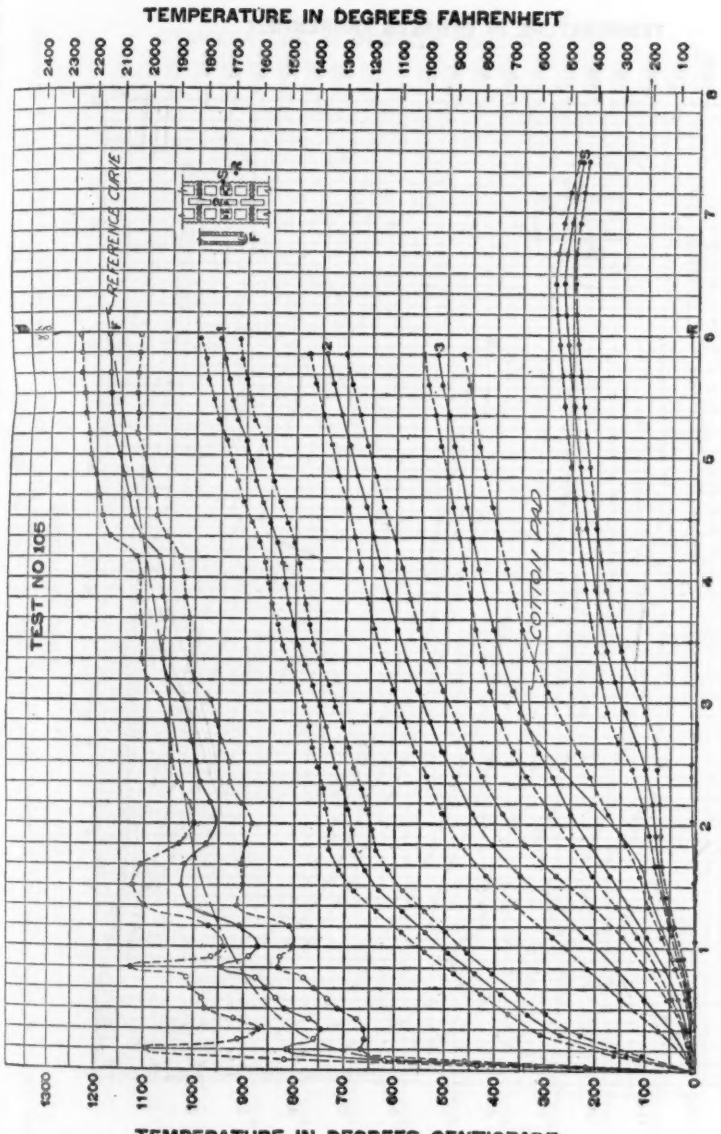


FIG. 124.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction* H*-shaped fire clay tile, source 1, test No. 105*

FIG. 123.—*Furnace and wall temperatures, 8-inch unplastered walls of side construction* H*-shaped fire clay tile, source 1, tests Nos. 103 and 104*

TIME IN HOURS

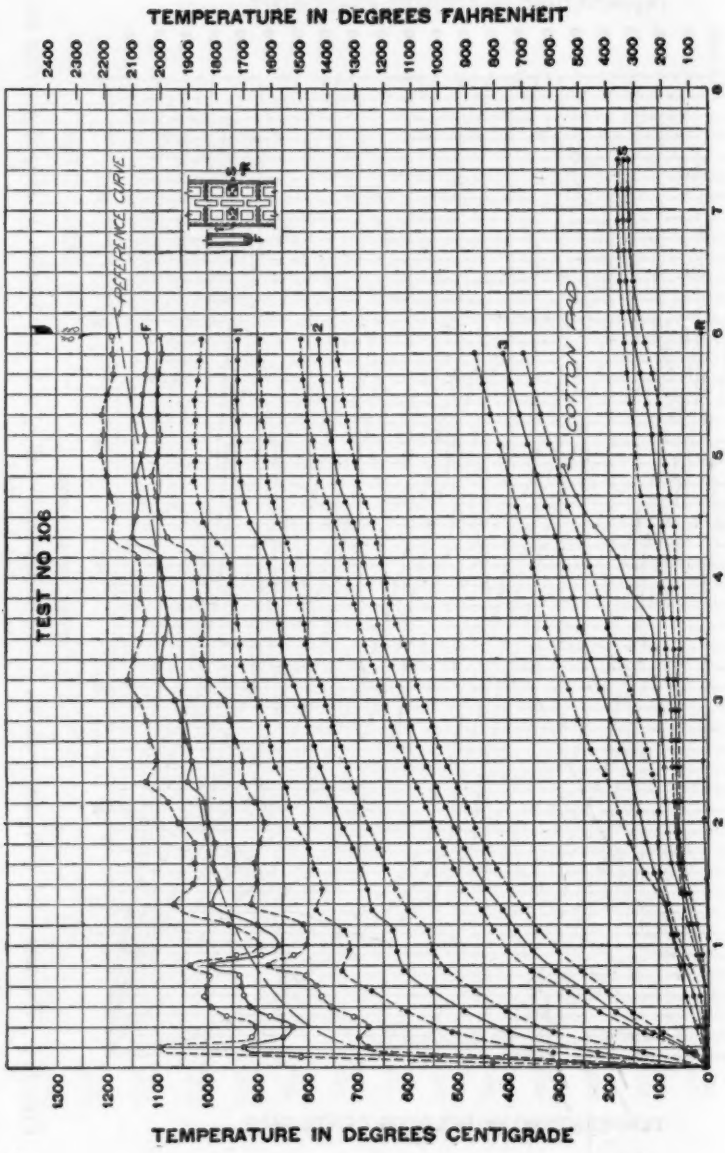


FIG. 125.—*Furnace and wall temperatures, 8-inch wall of side construction H-shaped fire clay tile, source l, gypsum plaster both sides, test No. 106*

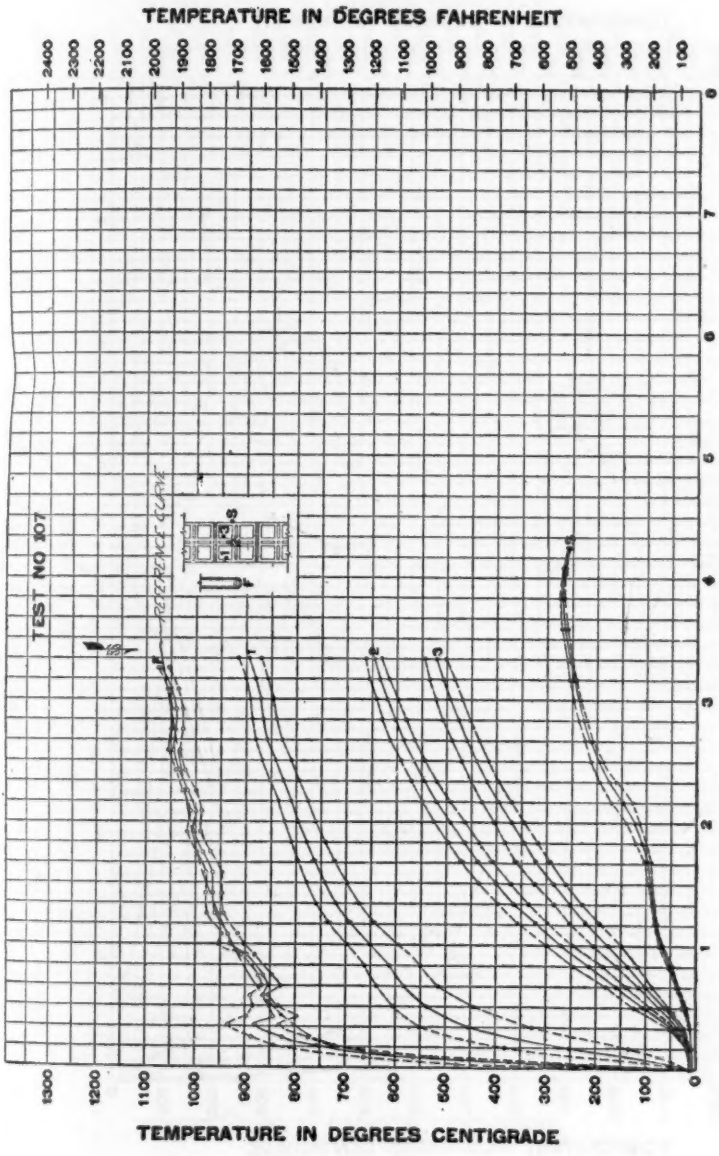


FIG. 126.—*Furnace and wall temperatures, 8-inch unplastered wall of side construction cube fire clay tile, source f, test No. 107*

FIG. 125.—*Furnace and wall temperatures, 8-inch wall of side construction cube fire clay tile, source f, plaster both sides, test No. 106*

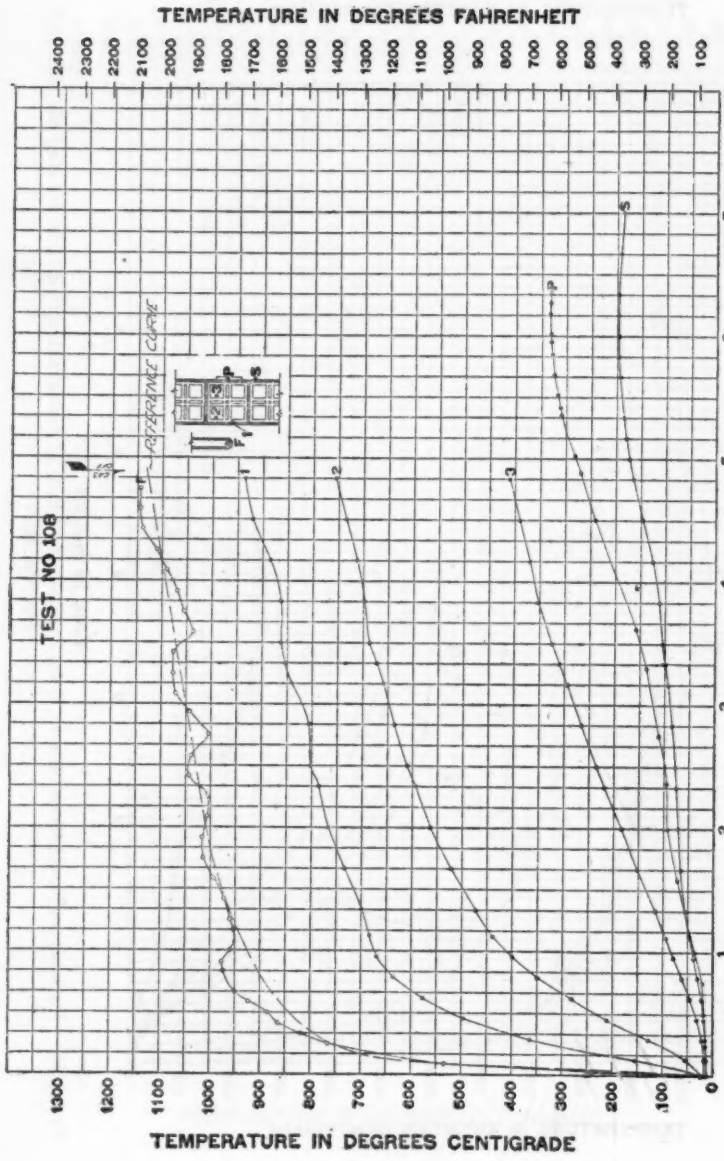


FIG. 127.—*Furnace and wall temperatures, 8-inch wall of side construction cube fire clay tile, source f, gypsum plaster both sides, test No. 108*

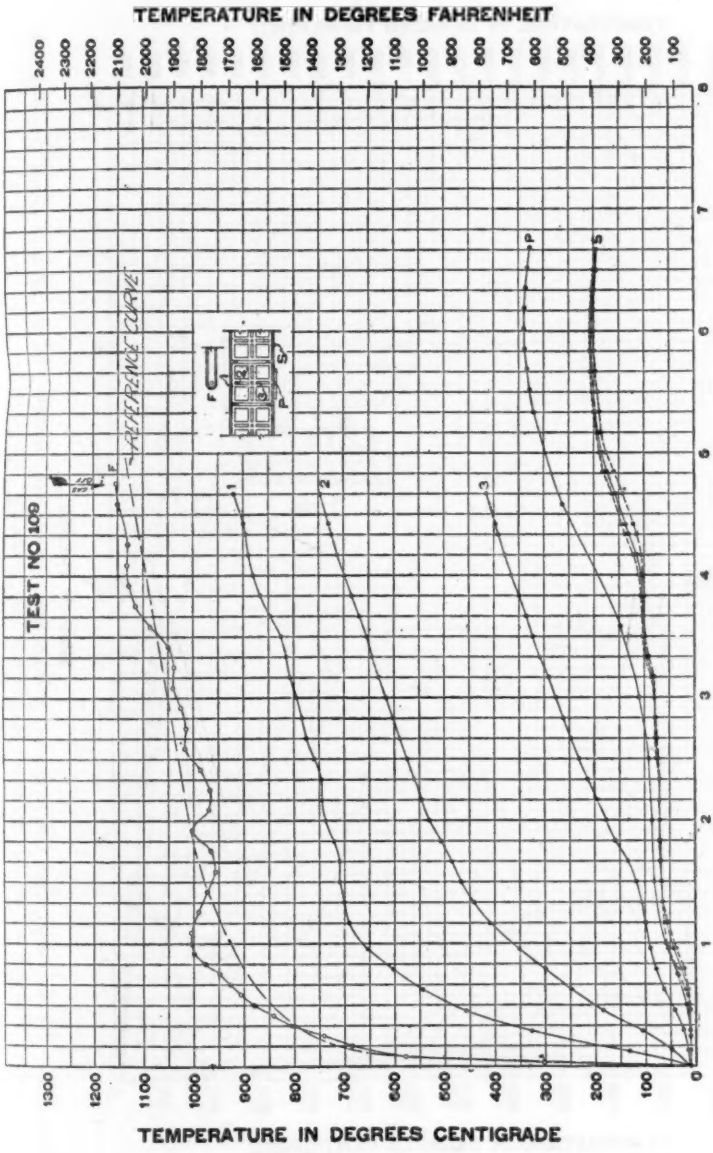


FIG. 128.—*Furnace and wall temperatures, 8-inch wall of side construction cube fire clay tile, source f, set on end, gypsum plaster both sides, test No. 109*

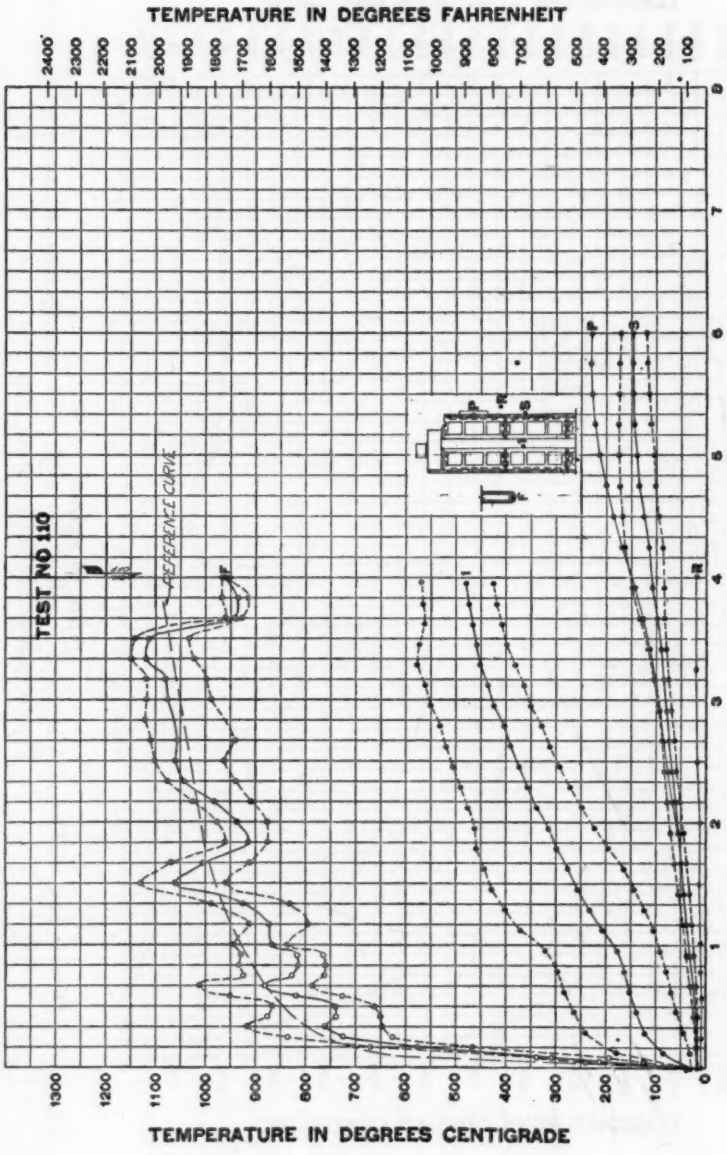


Fig. 129.—*Furnace and wall temperatures, 10-inch wall of end construction 3¾ by 12 inch 3-cell fire clay tile, source l, set on side, gypsum plaster fire side, cement plaster unexposed side, test No. 110*

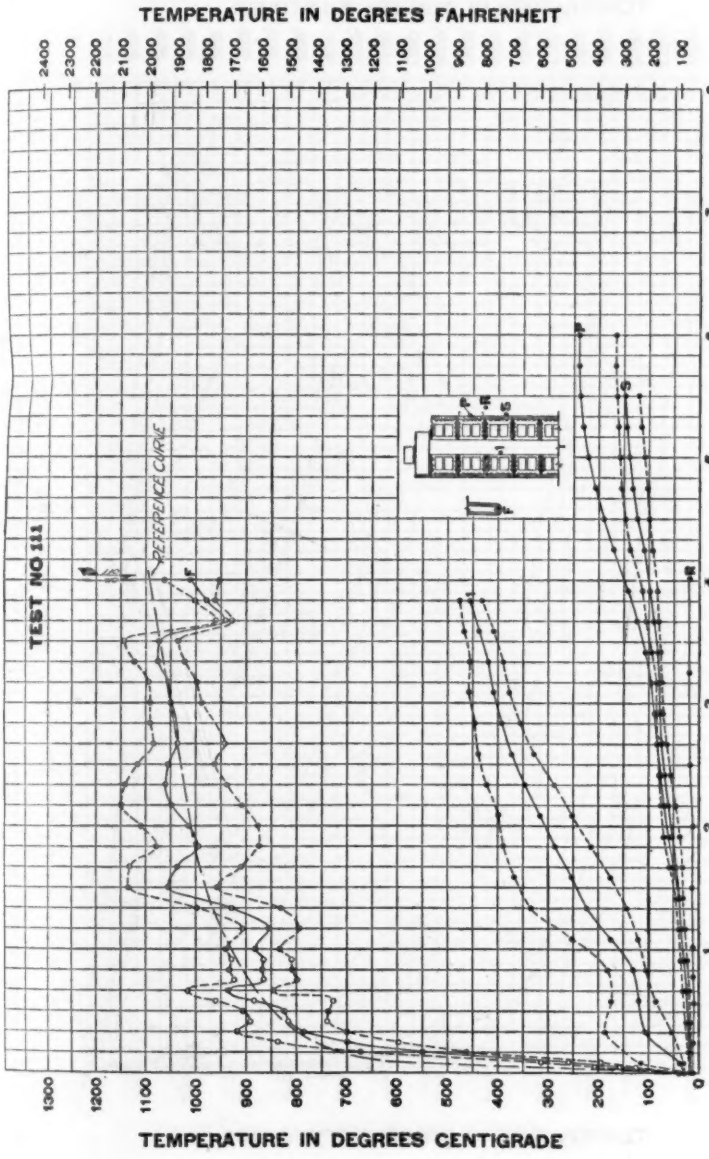


FIG. 130.—*Furnace and wall temperatures, 10-inch wall of side construction 2¾ by 5 inch fire clay tile, source l, gypsum plaster fire side, cement plaster unexposed side, test No. 111*

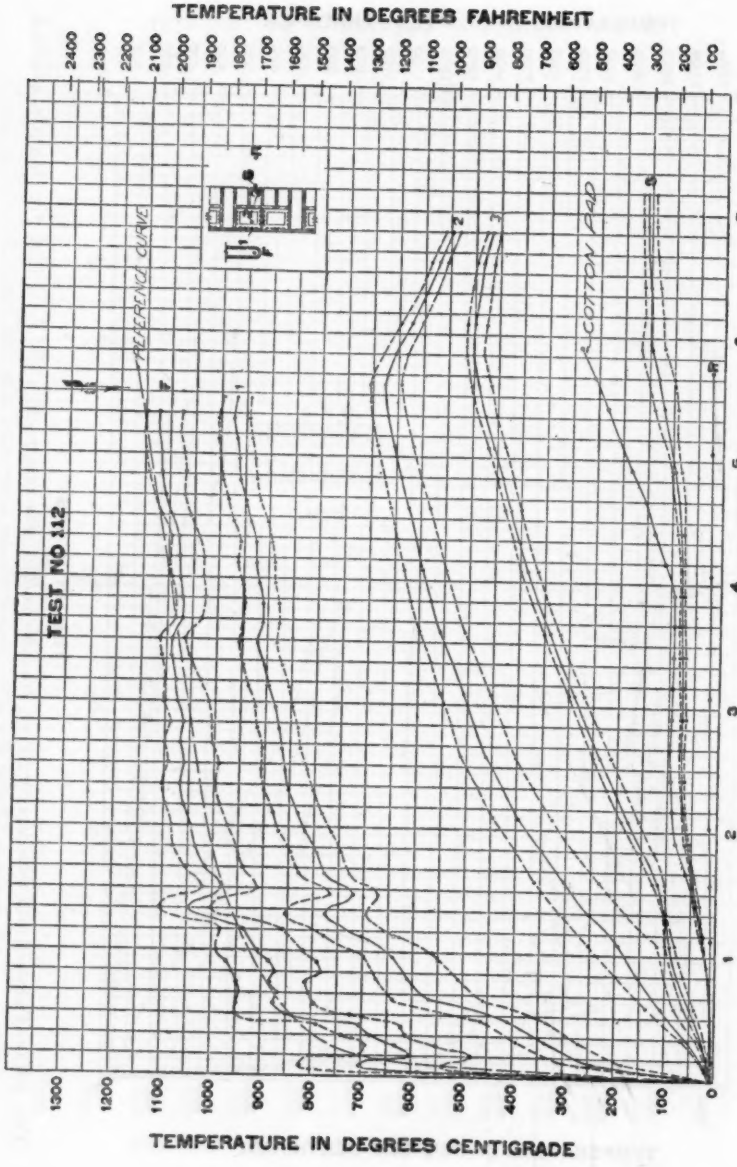


FIG. 131.—*Furnace and wall temperatures, brick-faced 8-inch wall backed with tile construction 3¾ by 5 inch, 1-cell fire clay tile, source m, gypsum plaster fire side, test No. 112*

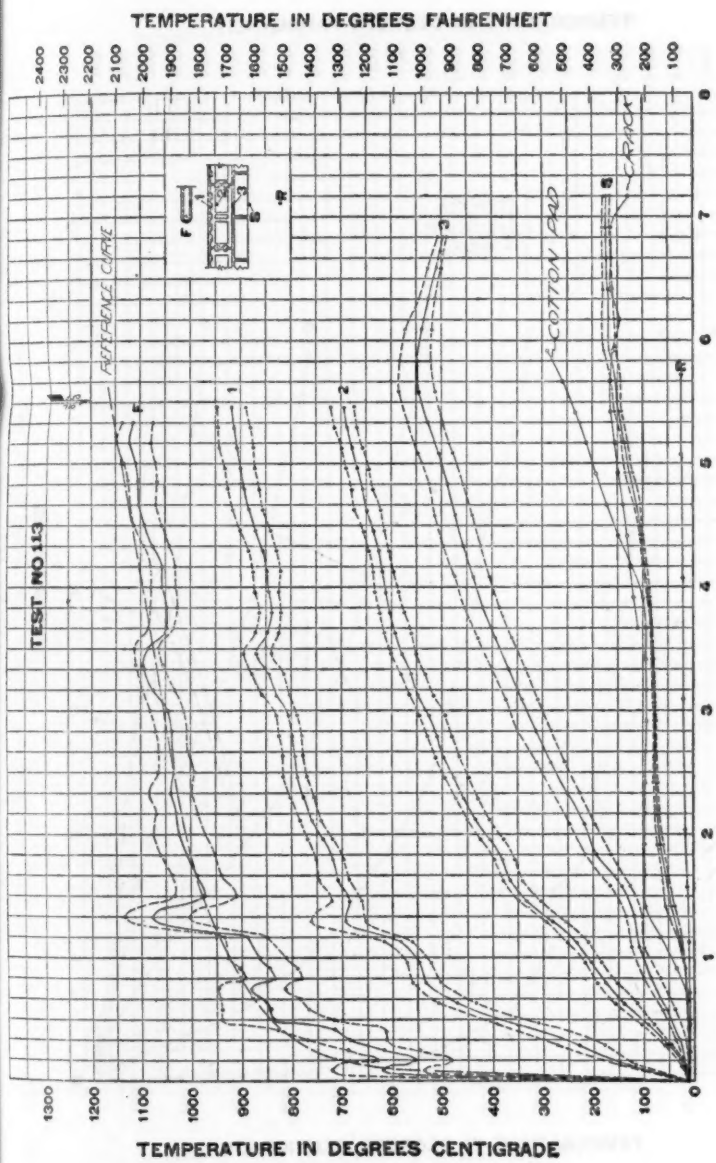


FIG. 132.—*Furnace and wall temperatures, brick-faced 8-inch wall backed with end construction 3-cell fire clay tile, source m, gypsum plaster fire side, test No. 113*

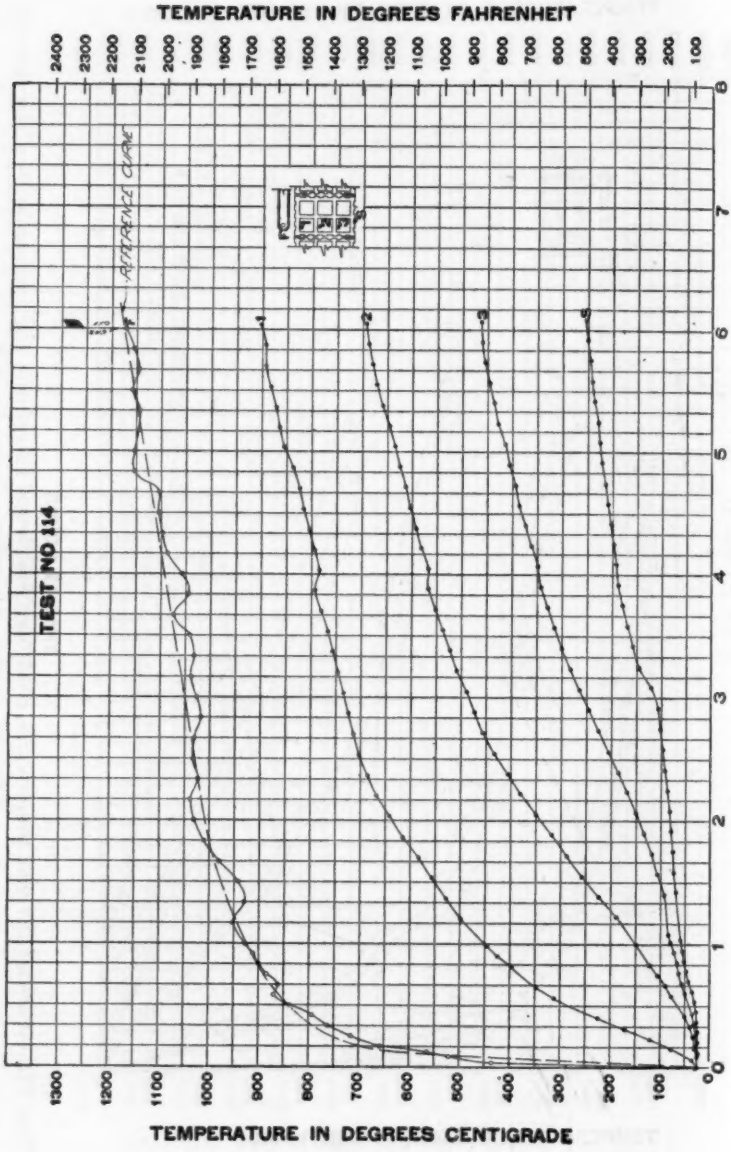


FIG. 133.—*Furnace and wall temperatures, 12-inch unplastered wall of end construction 6-cell shale tile, source d, test No. 114.*

FIG. 133.—*Furnace and wall temperatures, 12-inch unplastered wall of end construction 6-cell shale tile, source d, test No. 114*

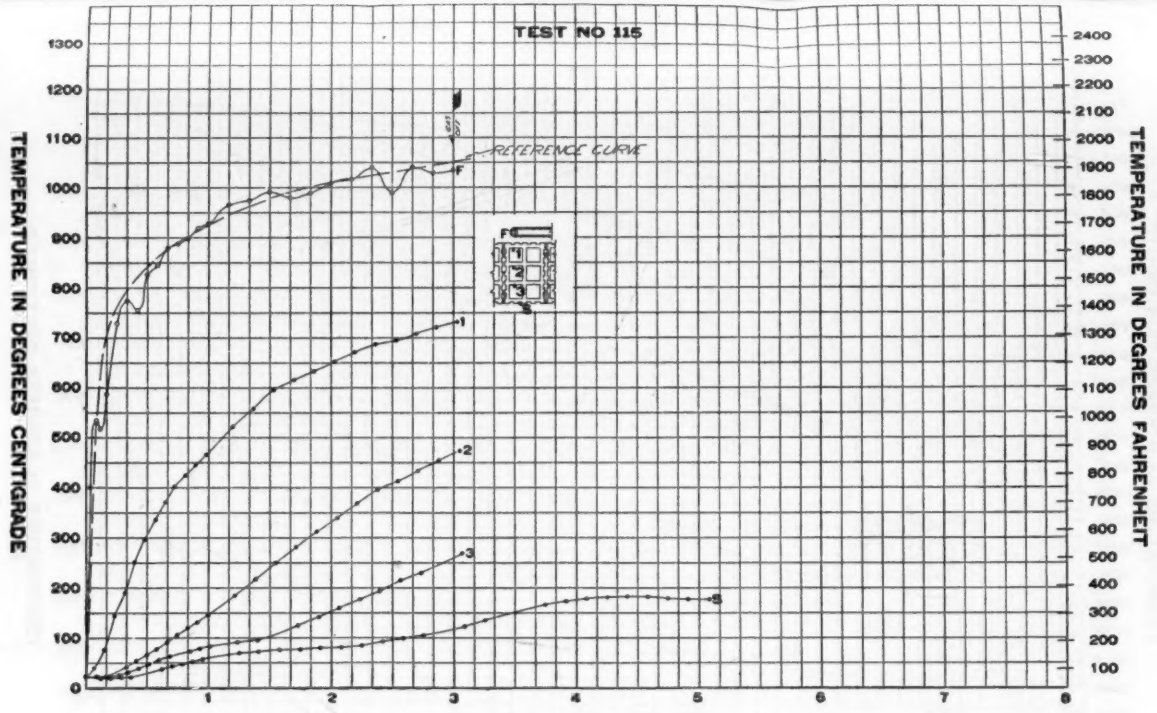


FIG. 134.—*Furnace and wall temperatures, 12-inch unplastered wall of end construction 6-cell shale tile, source d, test No. 115*

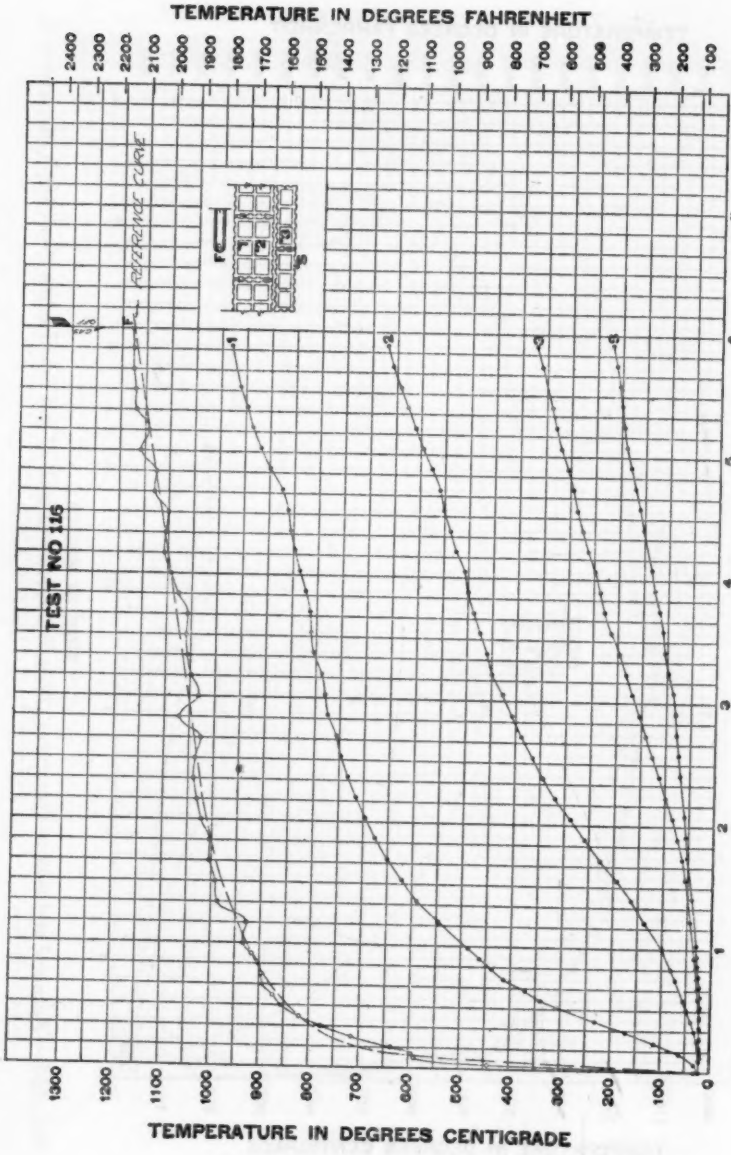
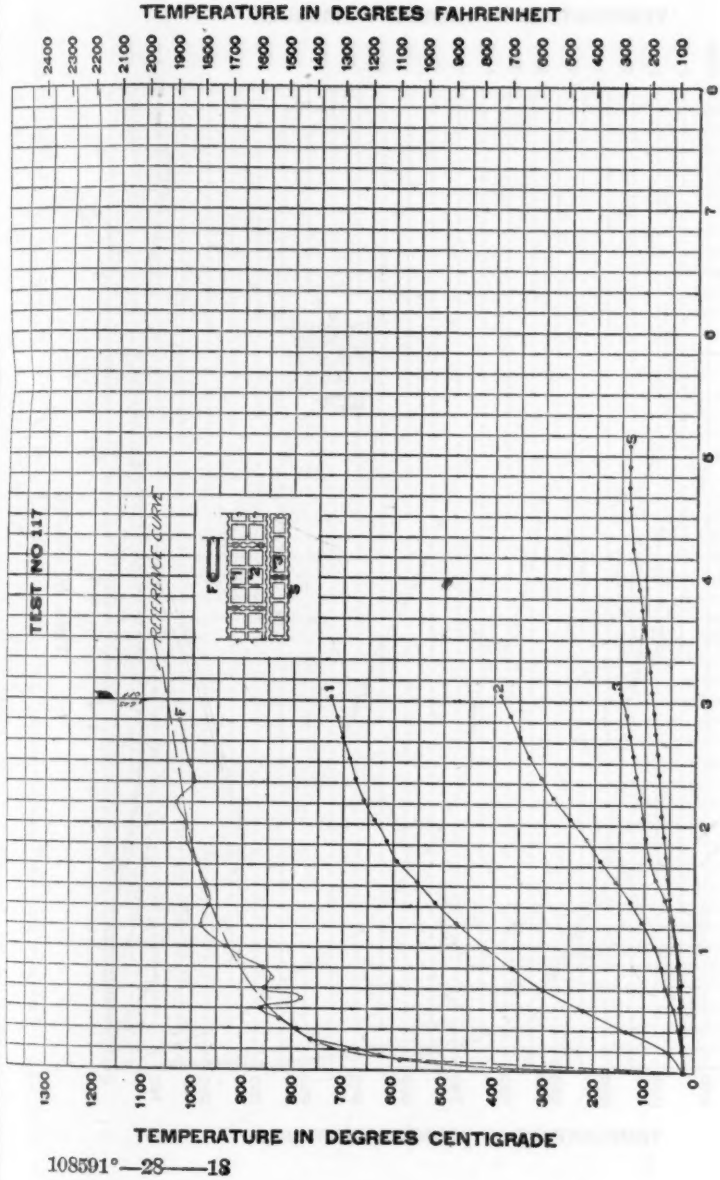


FIG. 135.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction 6-cell and 3-cell shale tile, source d, test No. 116*



108591°—28——18

FIG. 135.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction 6-cell and 3-cell shale tile, source d, test No. 116*

FIG. 136.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction 6-cell and 3-cell shale tile, source d, test No. 117*

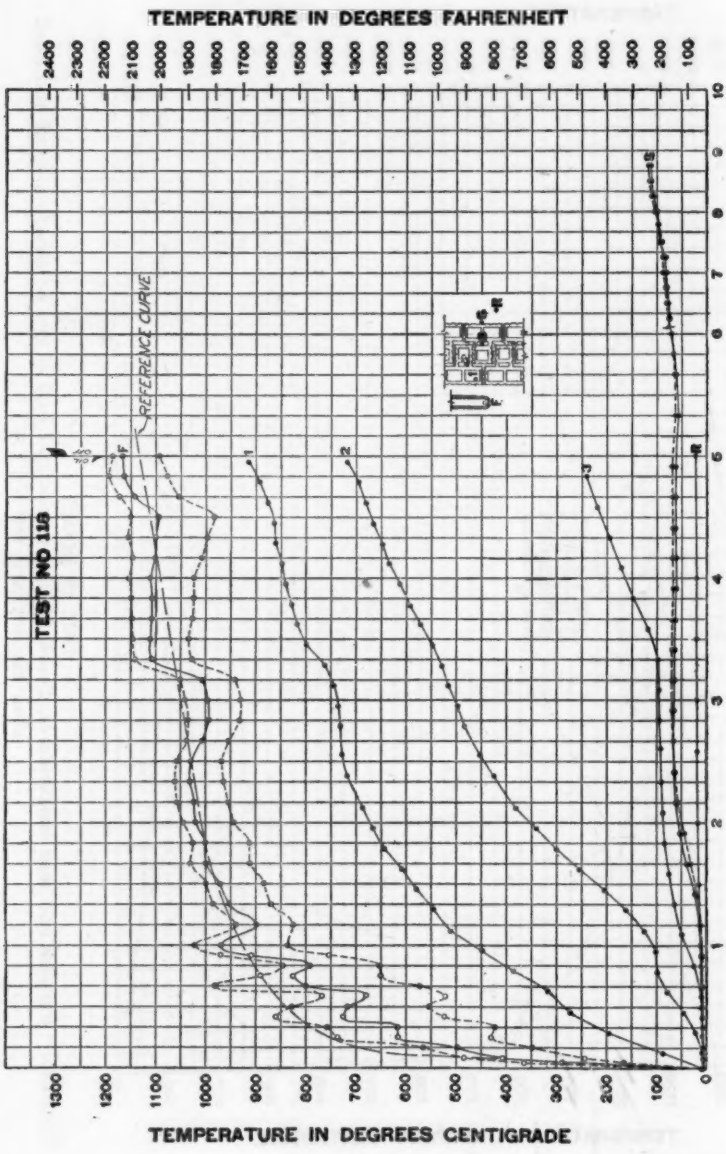


FIG. 137.—*Furnace and wall temperatures, 12-inch unplastered wall of side construction interlocking shale tile, source d–1, test No. 118*

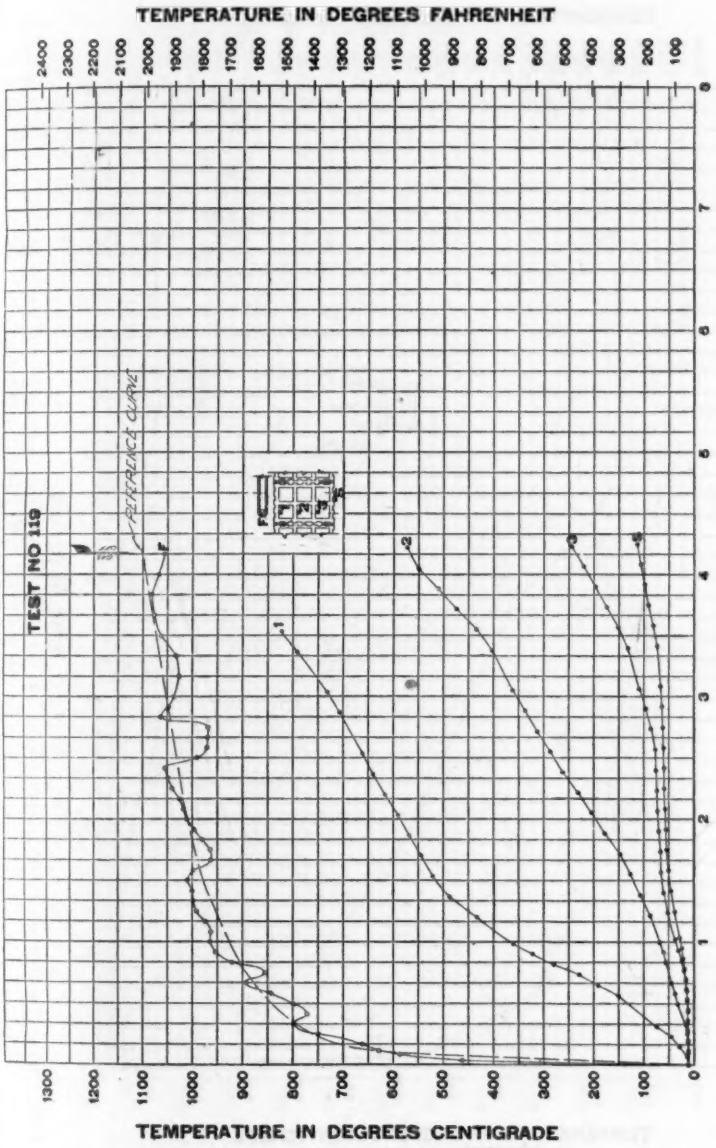


FIG. 138—*Furnace and wall temperatures, 12-inch unplastered wall of end construction 9-cell surface clay tile, source j, test No. 119*

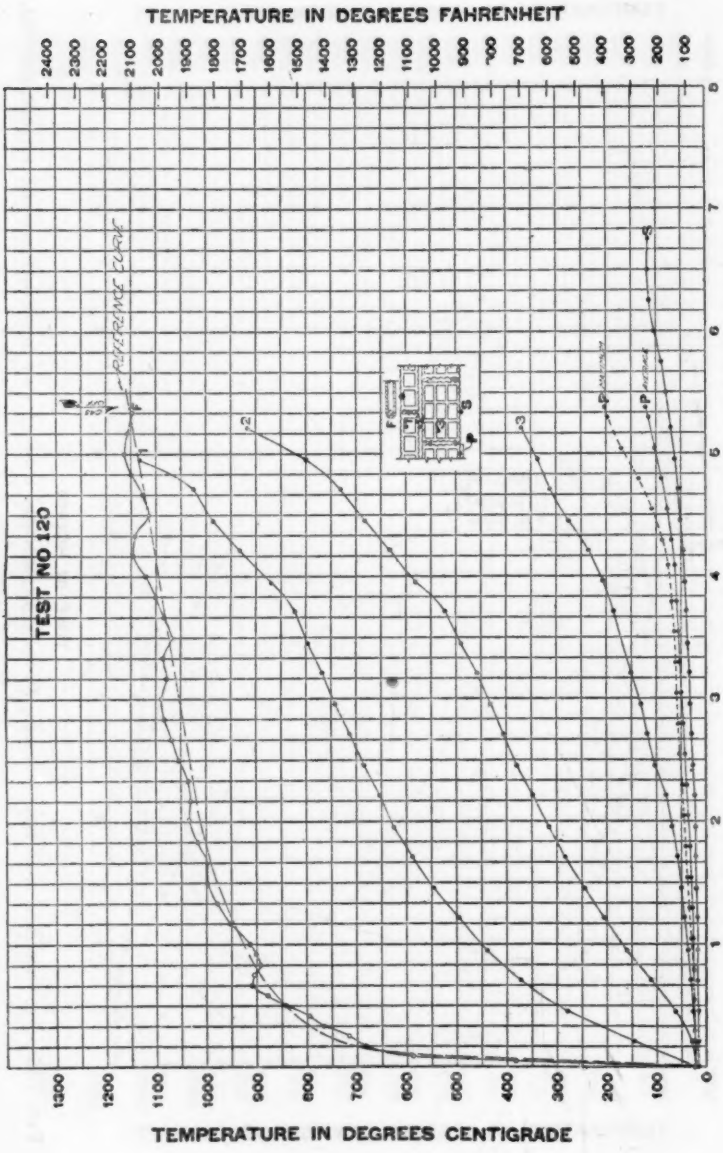


FIG. 139.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction 9-cell and 3-cell surface clay tile, source J, test No. 120*

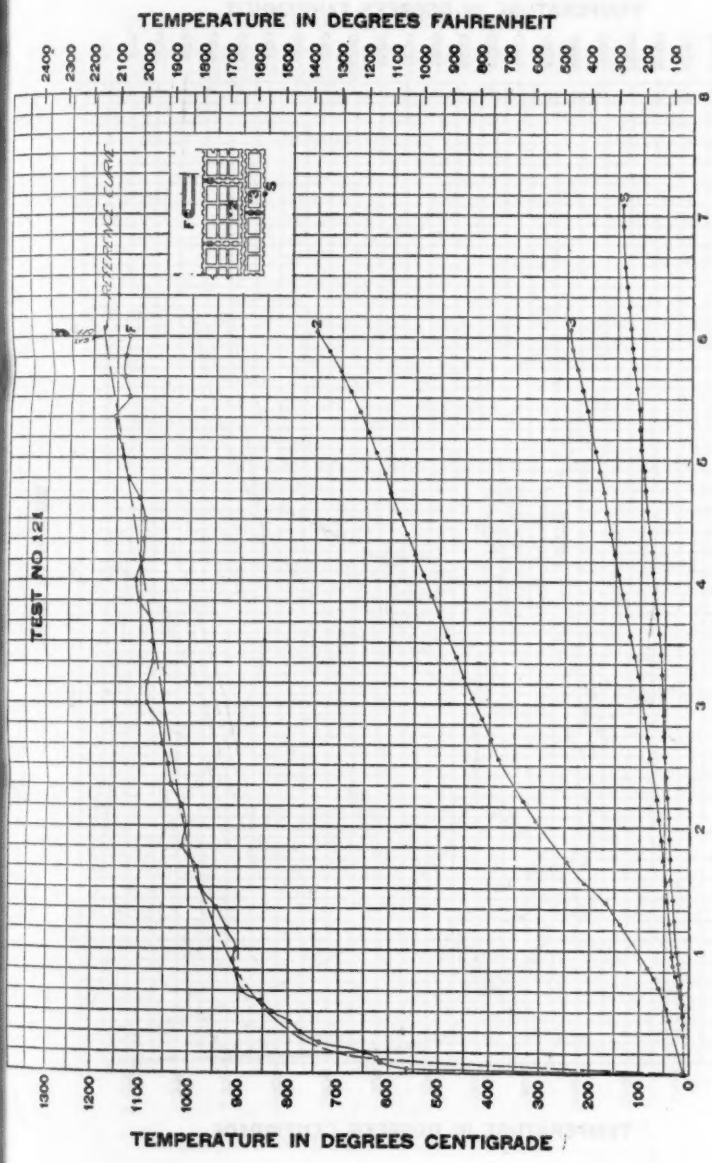


FIG. 140.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction 9-cell and 3-cell surface clay tile, source j, test No. 121*

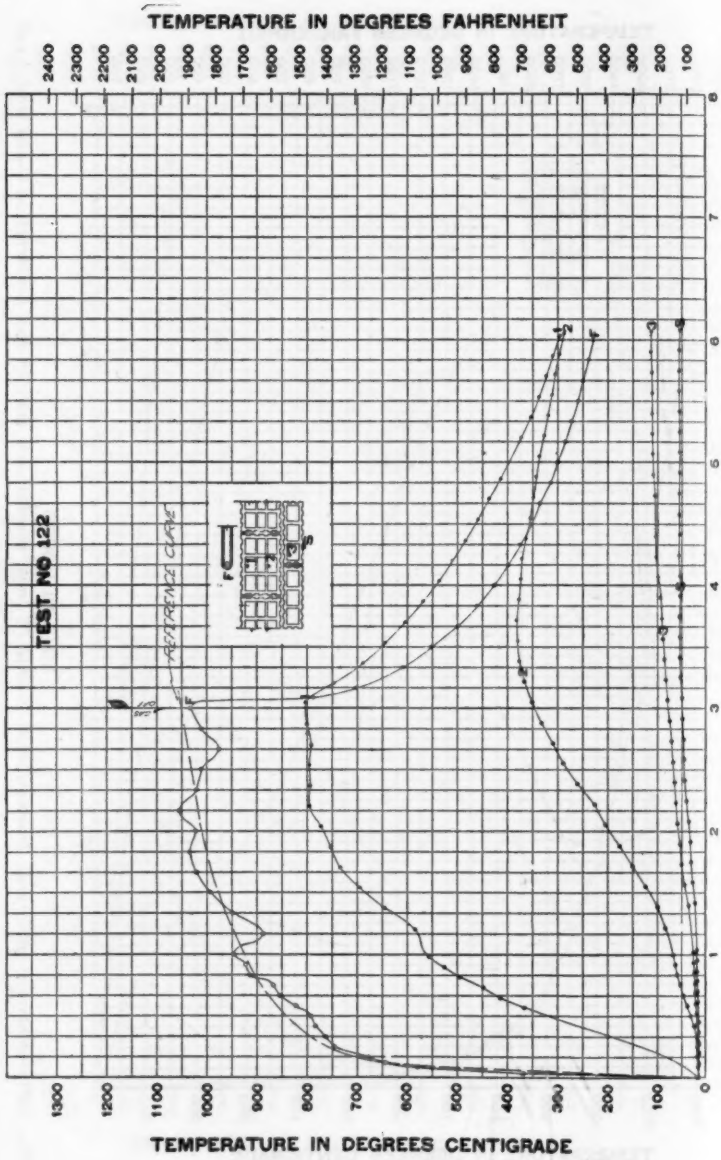


FIG. 141.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction 9-cell and 3-cell surface shut flue, course 1, test No. 122*

FIG. 141.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction 9-cell and 3-cell surface clay tile, source j, test No. 122*

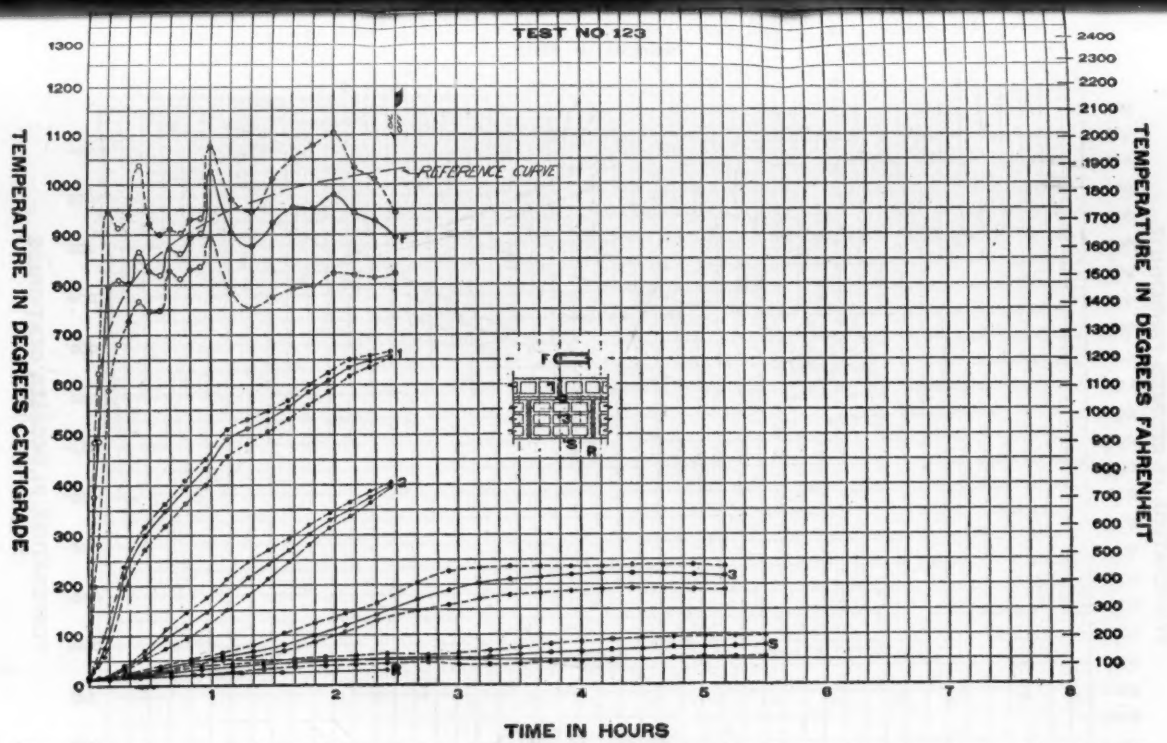


FIG. 142.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction 9-cell and 3-cell surface clay tile, source j, test No. 123*

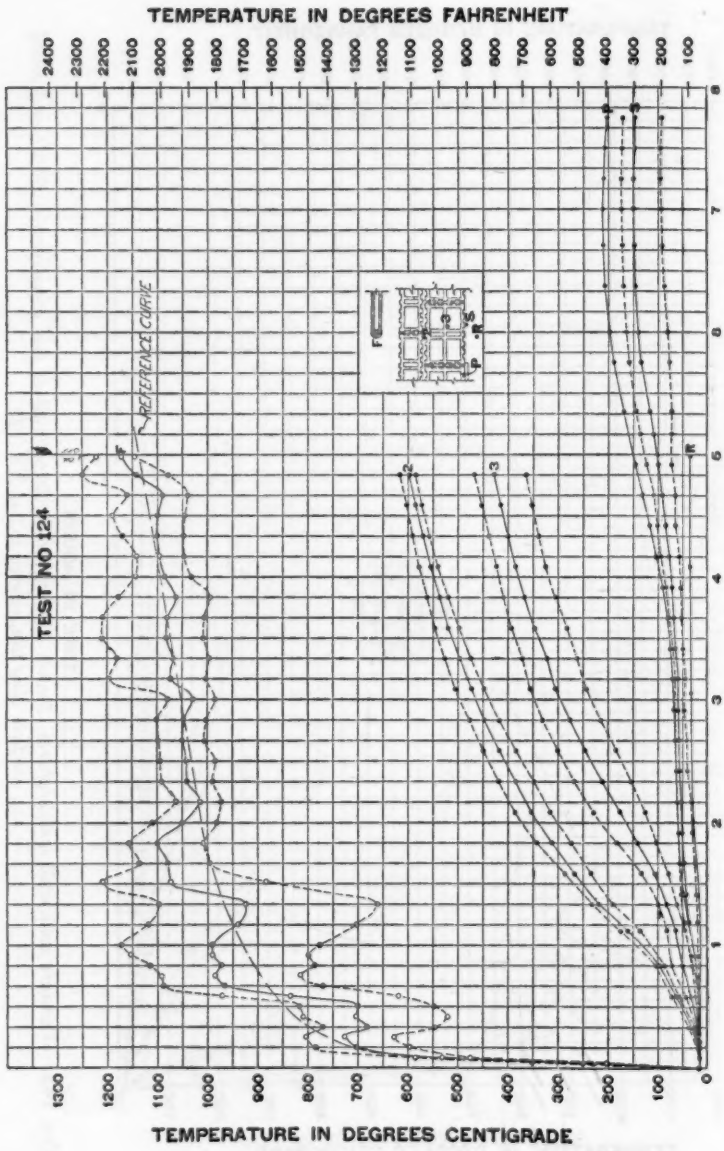


FIG. 143.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction "xx" 6-cell and 3-cell surface clay tile, source K, test No. 124*

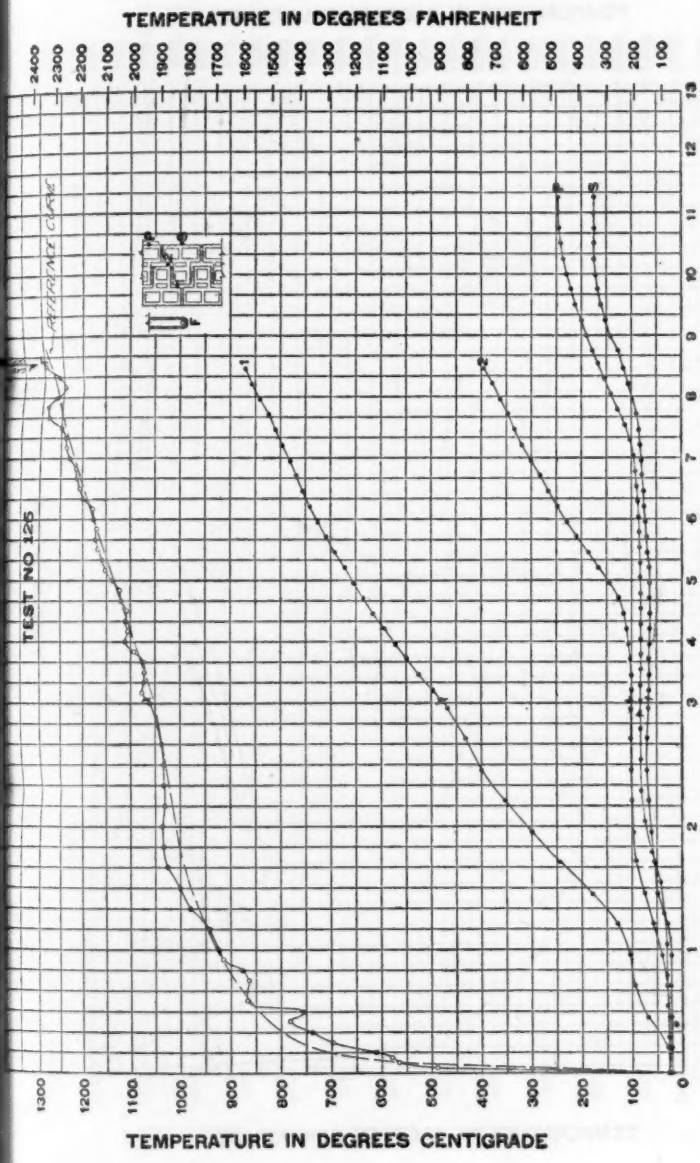


FIG. 144.—*Furnace and wall temperatures, 12-inch unplastered wall of side construction interlocking surface clay tile, source p–1, test No. 125*

FIG. 143.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction "zzz" 6-cell and 3-cell surface clay tile, source k, test No. 125*

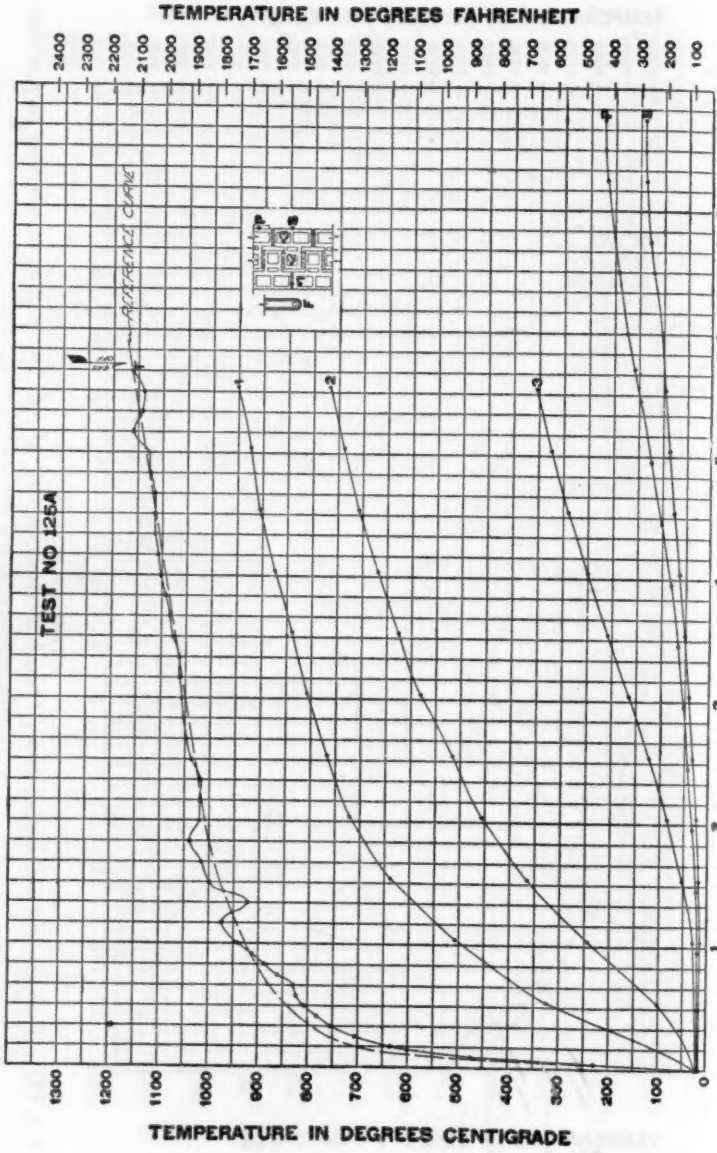


FIG. 145.—*Furnace and wall temperatures, 12-inch unplastered wall of side construction interlocking surface clay*

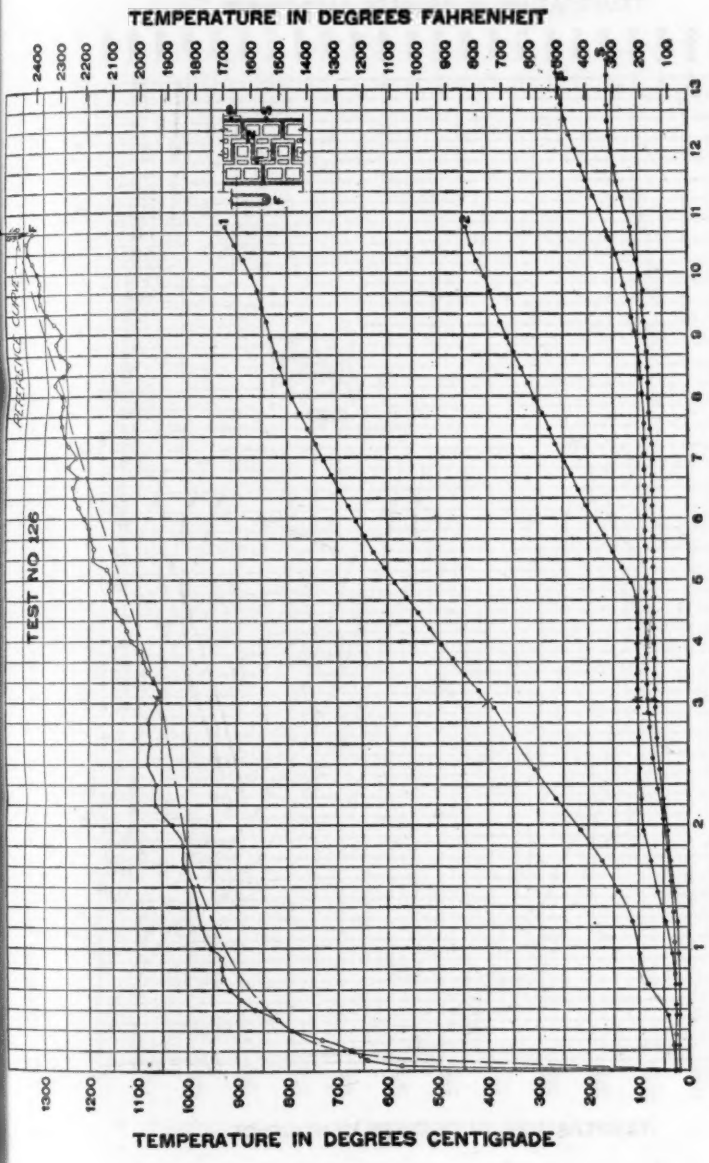


FIG. 146.—*Furnace and wall temperatures, 12-inch wall of side construction interlocking surface clay tile, source p–1, gypsum plaster both sides, test No. 126*

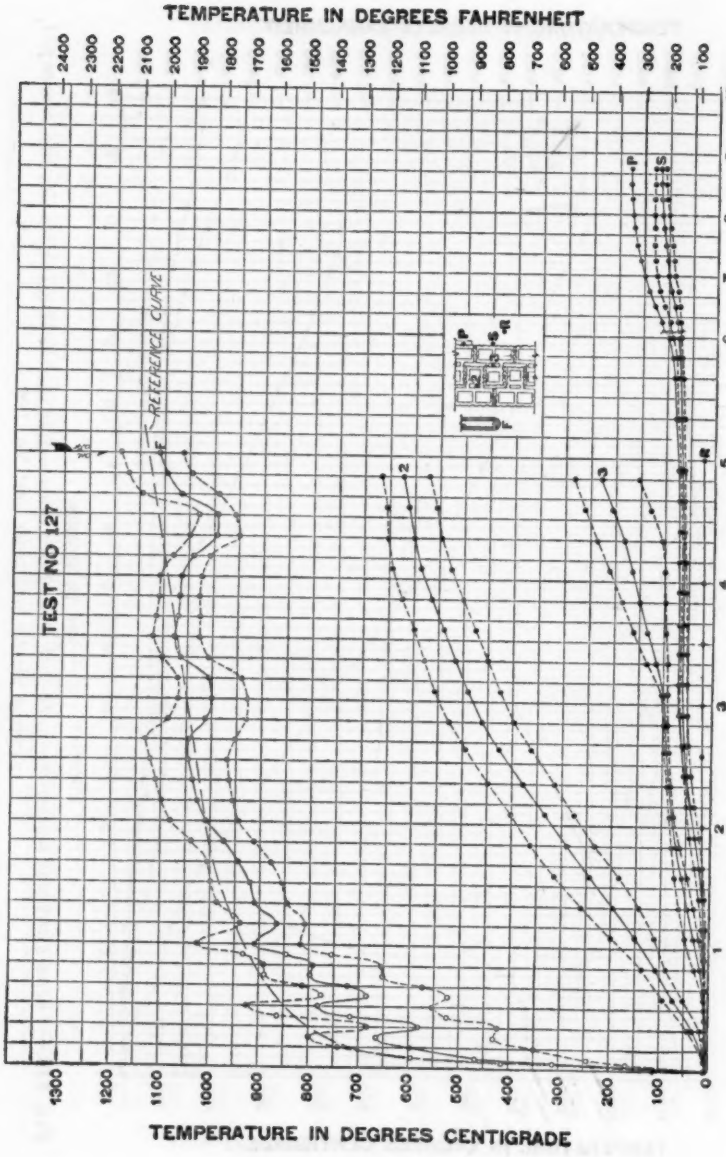


FIG. 147.—*Furnace and wall temperatures, 12-inch unplastered wall of side construction interlocking surface clay tile, source 1–4, test No. 127.*

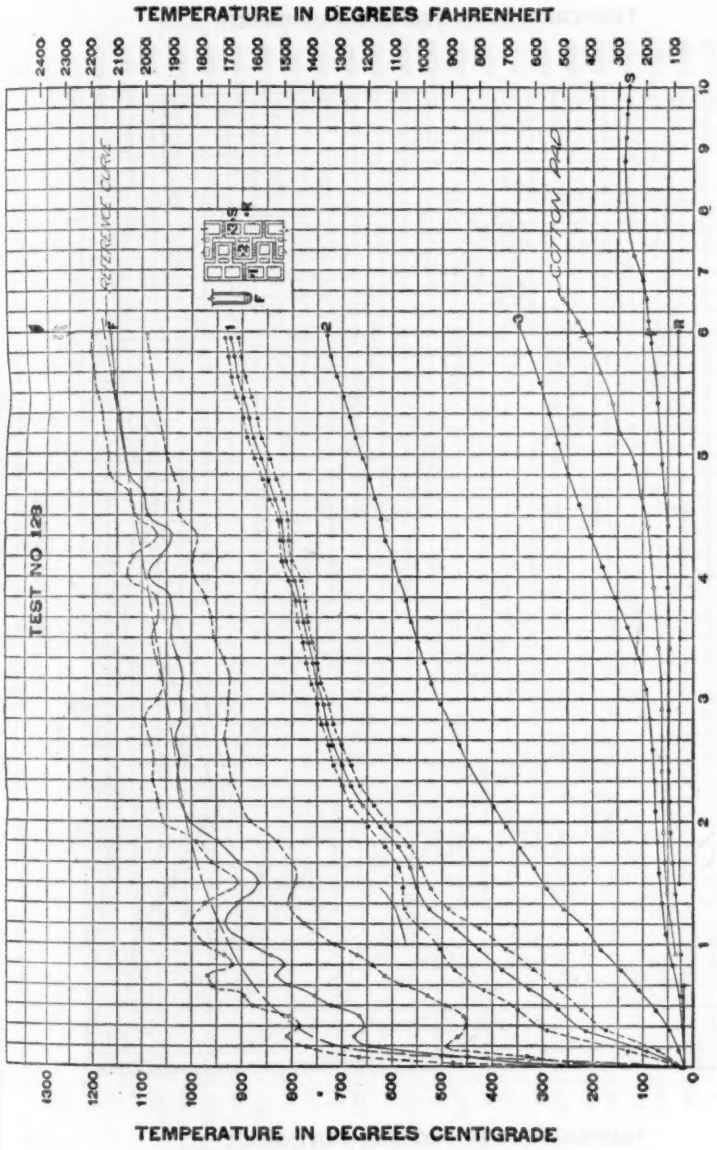


FIG. 148.—*Furnace and wall temperatures, 12-inch unplastered wall of side construction interlocking surface clay tile, source p–1, test No. 123*

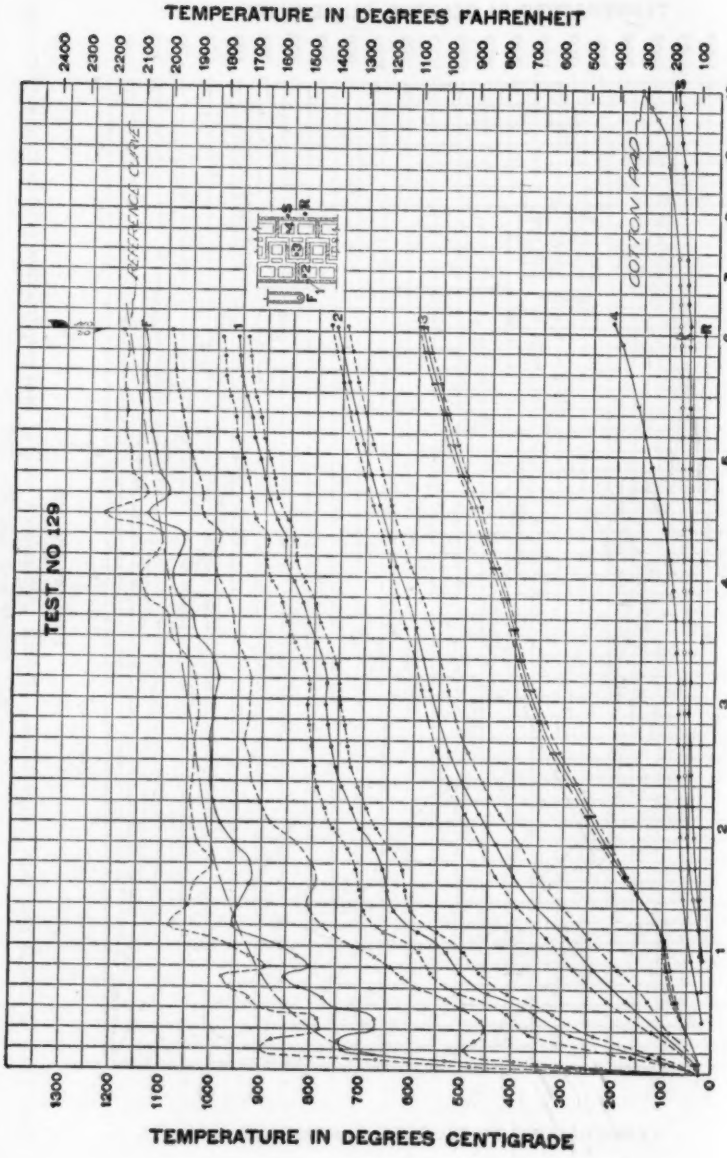


FIG. 149.—*Furnace and wall temperatures, 12-inch wall of side construction interlocking surface clay tile, source p–1, gypsum plaster both sides, test No. 129*

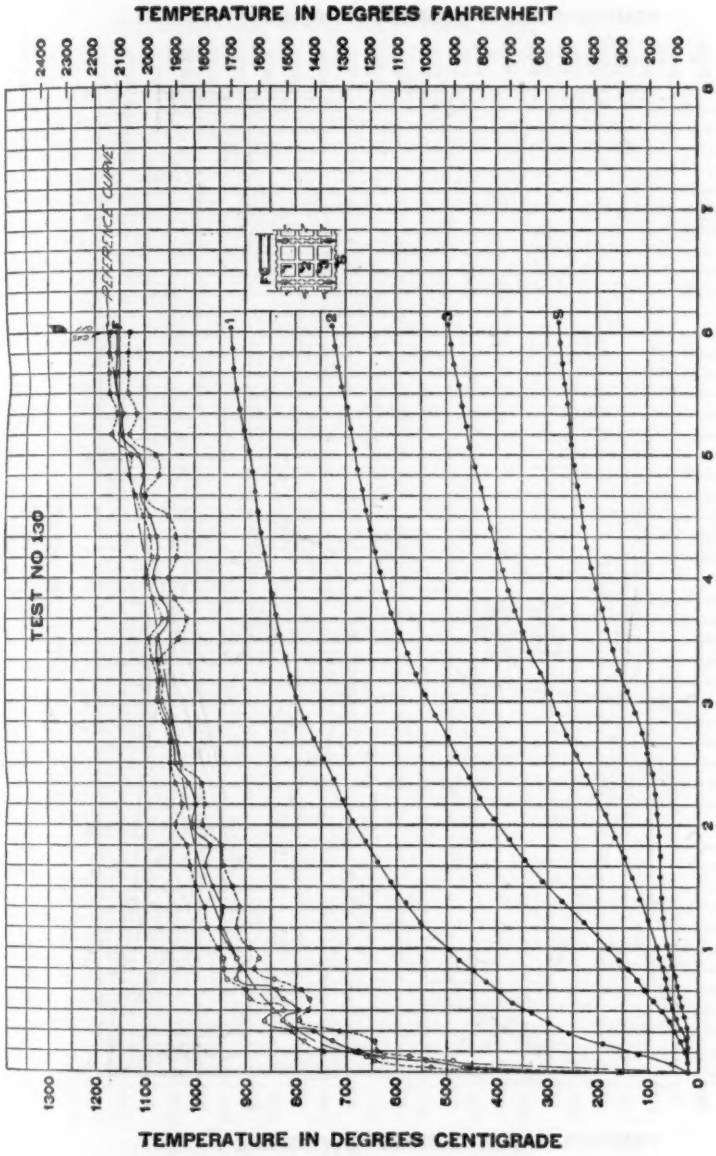


FIG. 150.—*Furnace and wall temperatures, 12-inch unplastered wall of end construction 6-cell fire clay tile, source 1, test No. 130*

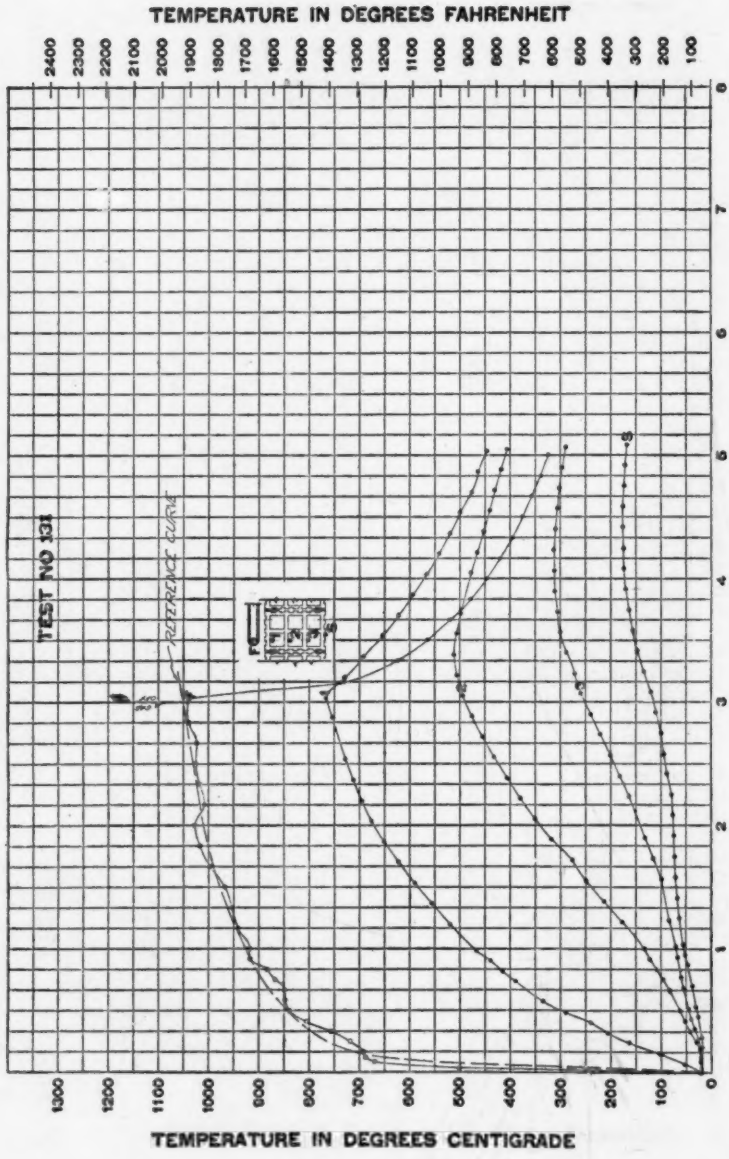


FIG. 151.—*Furnace and wall temperatures. 12-inch unplastered wall of end construction 6-cell fire clay tile, source 1, test No. 131*

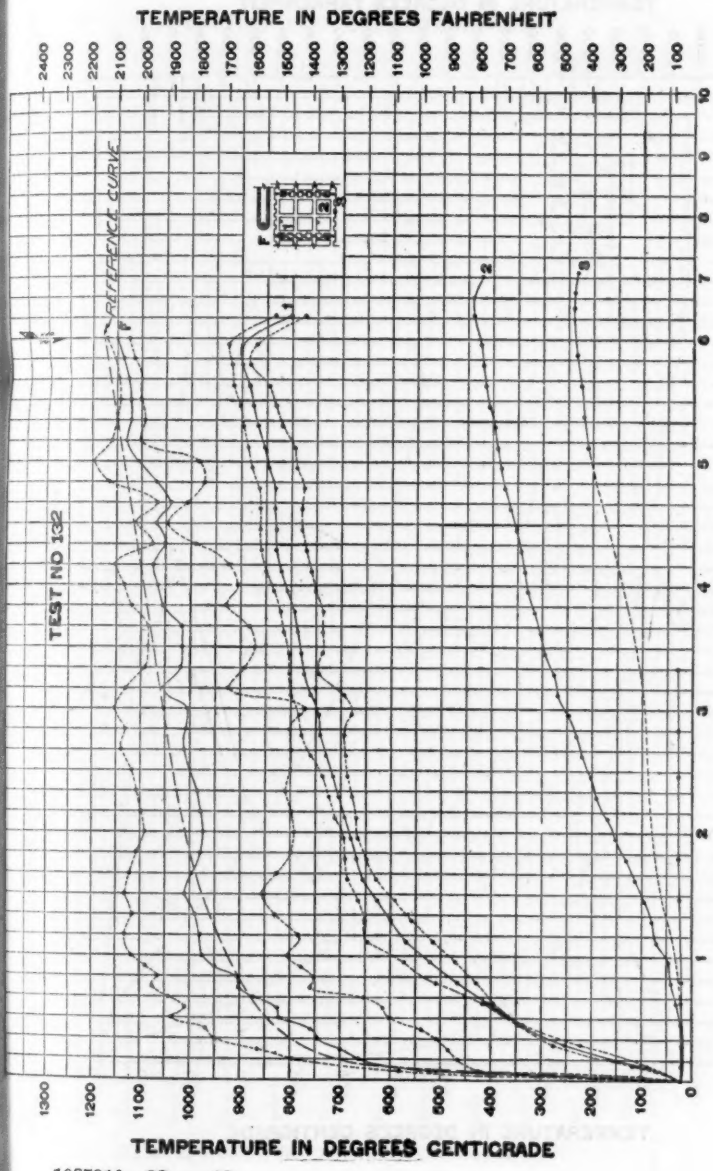


FIG. 152.—*Furnace and wall temperatures, 12-inch unplastered wall of end construction 6-cell fire clay tile, source l, test No. 132*

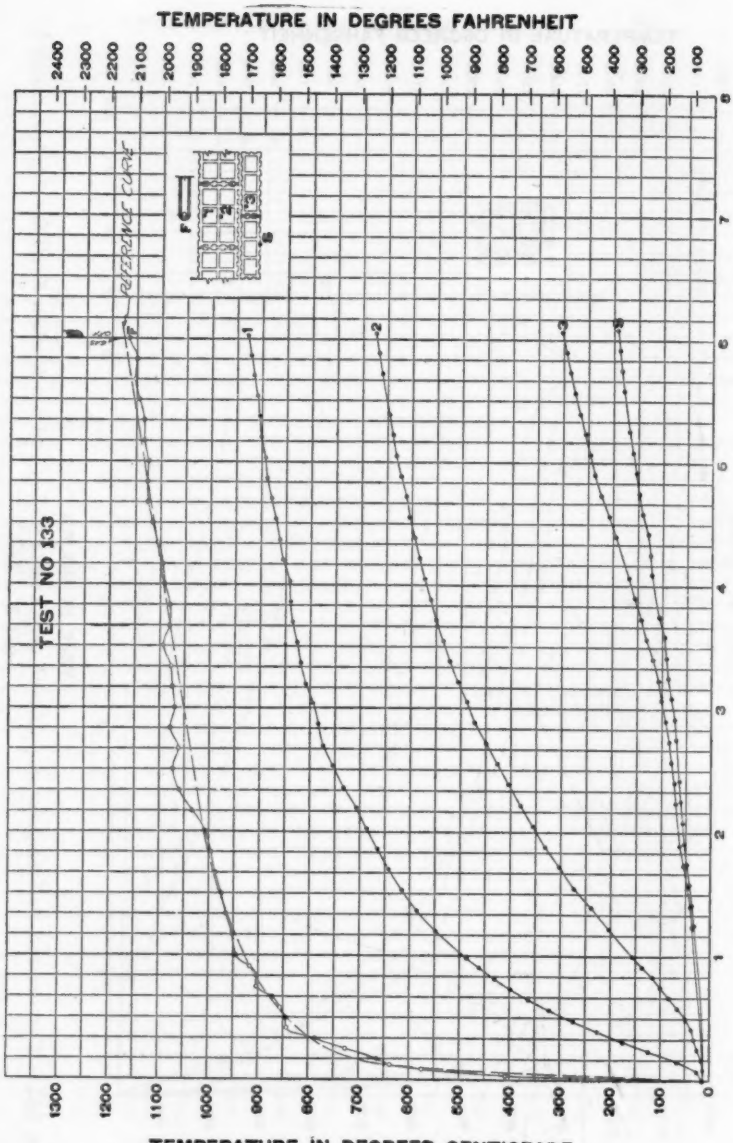


FIG. 153.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction 6-cell and 3-cell fire clay tile, source 1, test No. 133*

FIG. 153.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, source l, test No. 133*

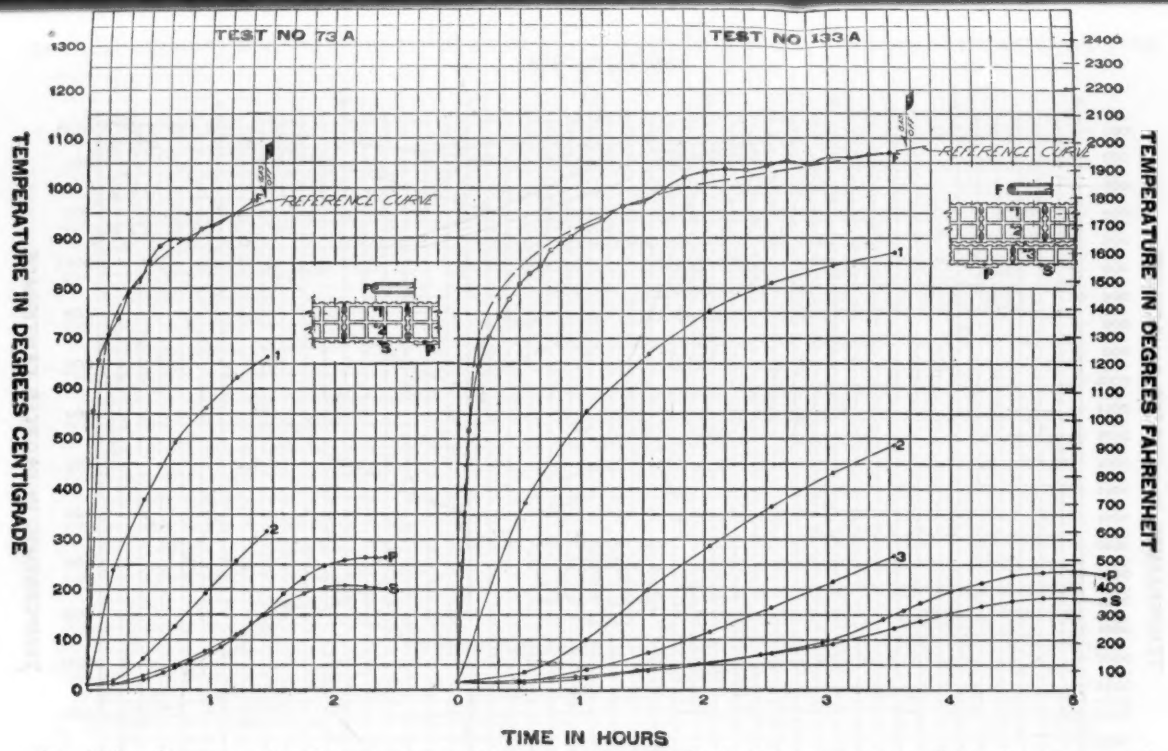


FIG. 154.—*Furnace and wall temperatures, 8-inch unplastered wall of end construction 6-cell fire clay tile, sourcel, dried to constant weight, test No. 73A; 2-unit 12-inch unplastered wall of end construction 6-cell and 3-cell fire clay tile, source l, dried to constant weight, test No. 133A*

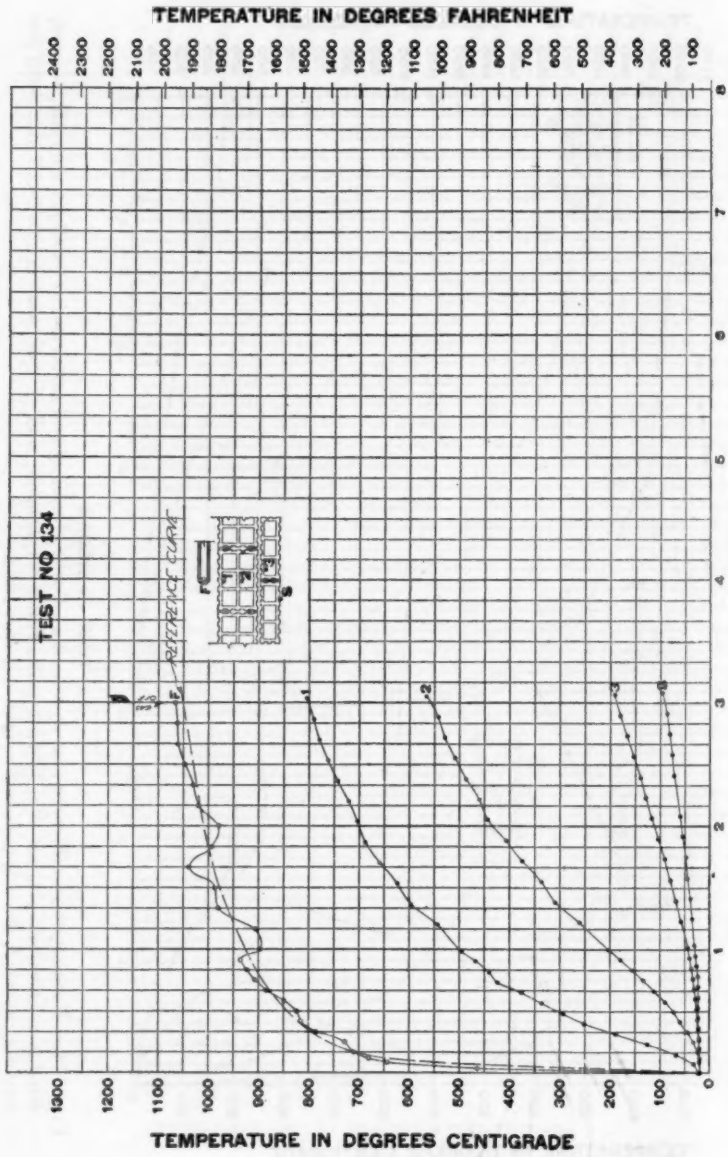


FIG. 155.—*Furnace and wall temperatures, 2-unit 12-inch unplastered wall of end construction 6-cell and 3-cell fire clay tile, source 1, test No. 134*

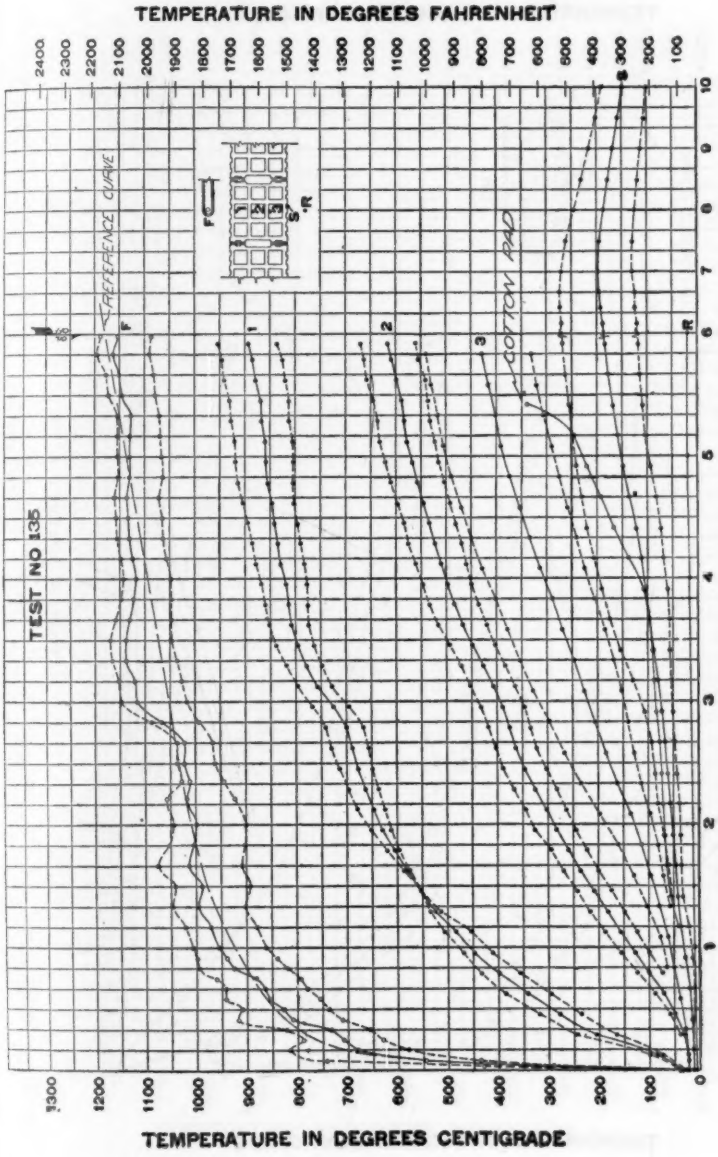


FIG. 156.—*Furnace and wall temperatures, 12-inch unplastered wall of end construction 9-cell fire clay tile, source n, test No. 135*

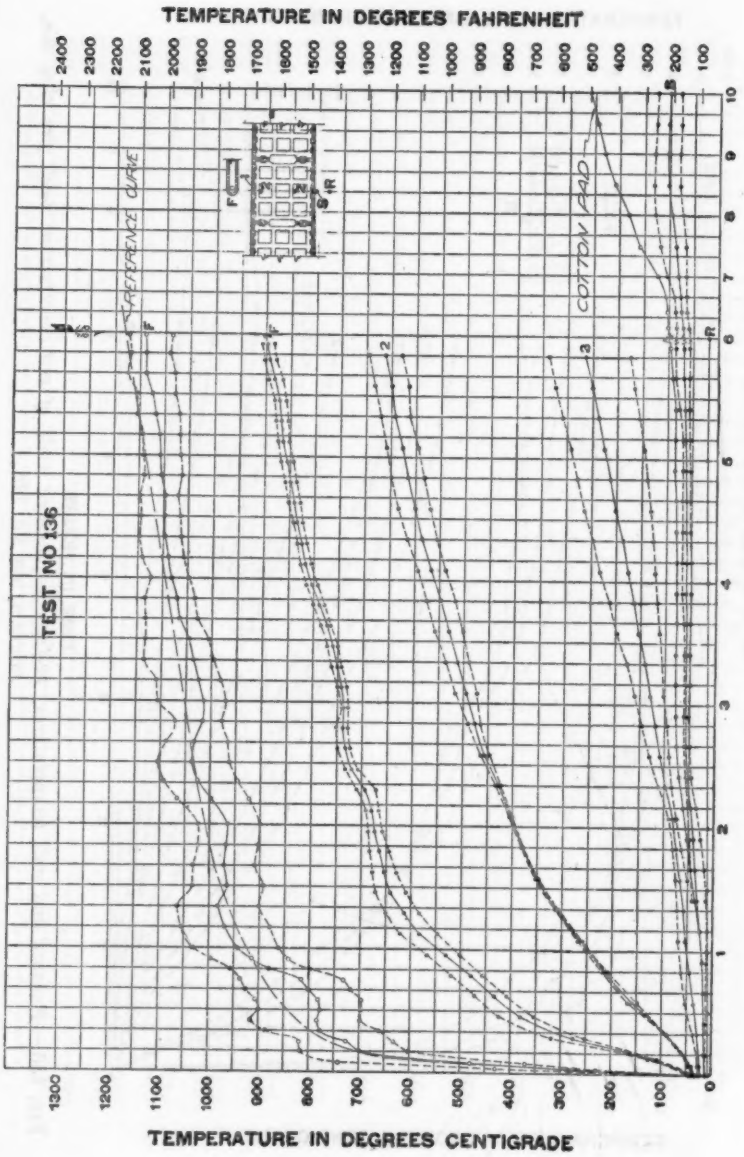


FIG. 157.—*Furnace and wall temperatures, 12-inch wall of end construction 3-cell fire clay tile, source n, gypsum plaster both sides, test No. 136*

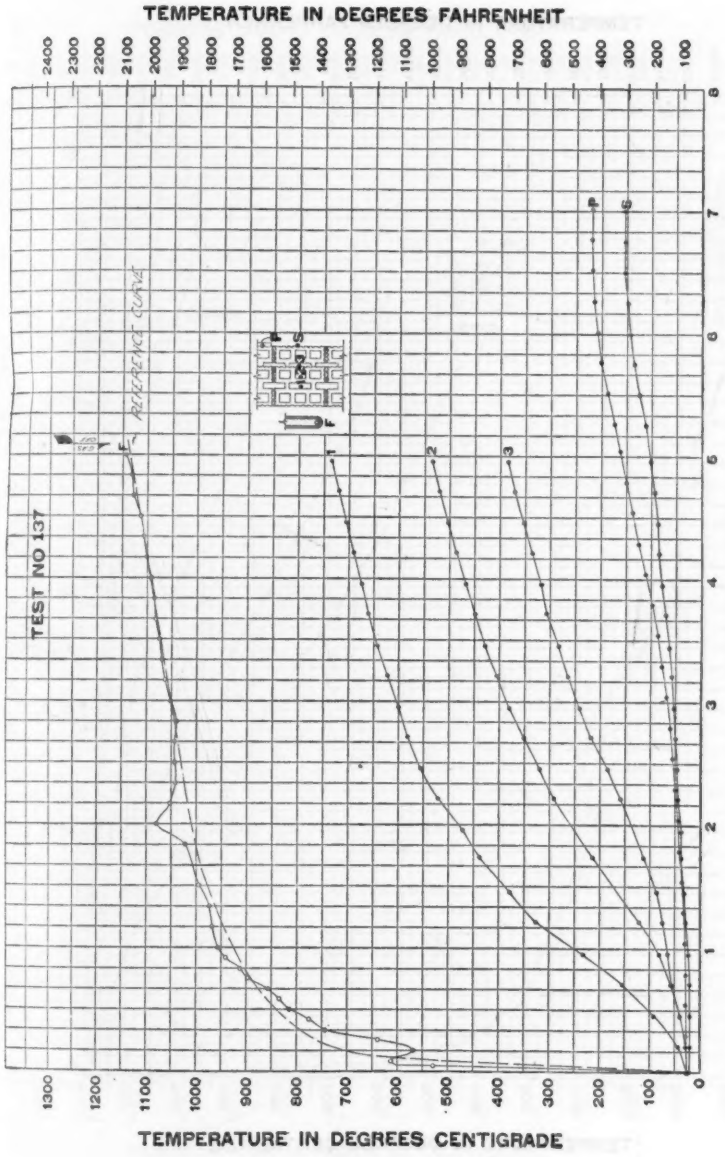


FIG. 158.—*Furnace and wall temperatures, 12-inch unplastered wall of side construction* H*-shaped fire clay tile, source l, test No. 137*

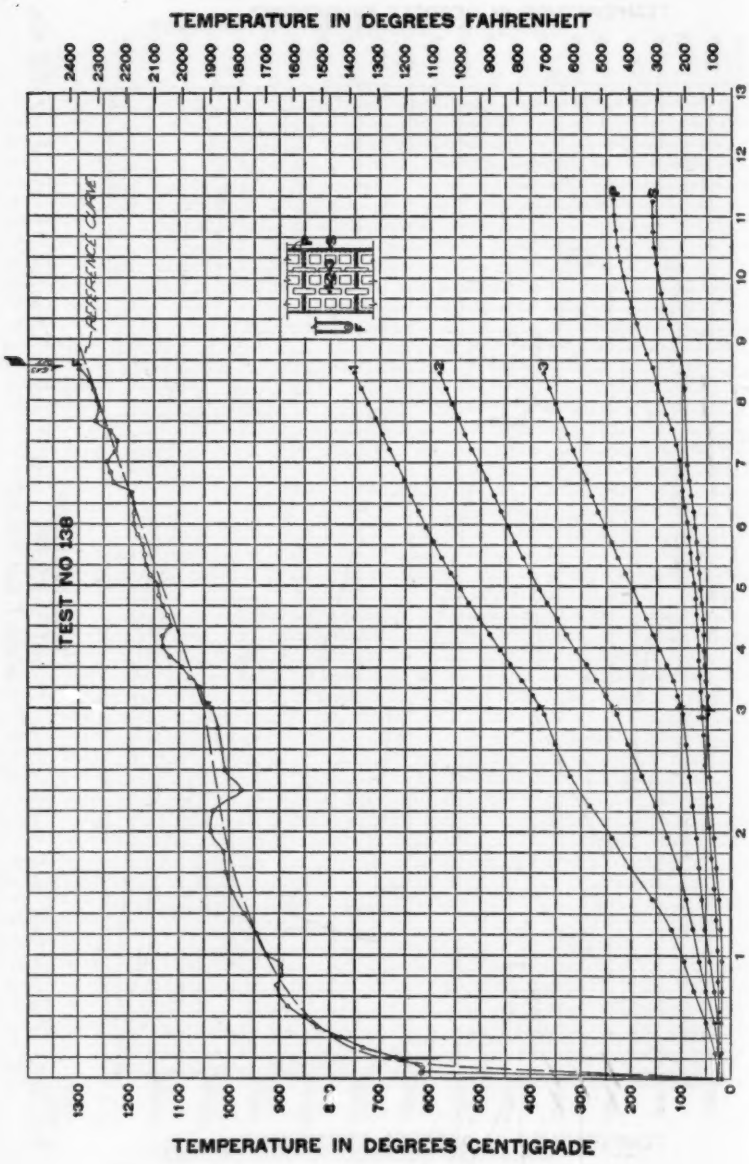


FIG. 159.—*Furnace and wall temperatures, 12-inch unplastered wall of side construction H-shaped fire clay tile, source I, gypsum plaster both sides, test No. 138*

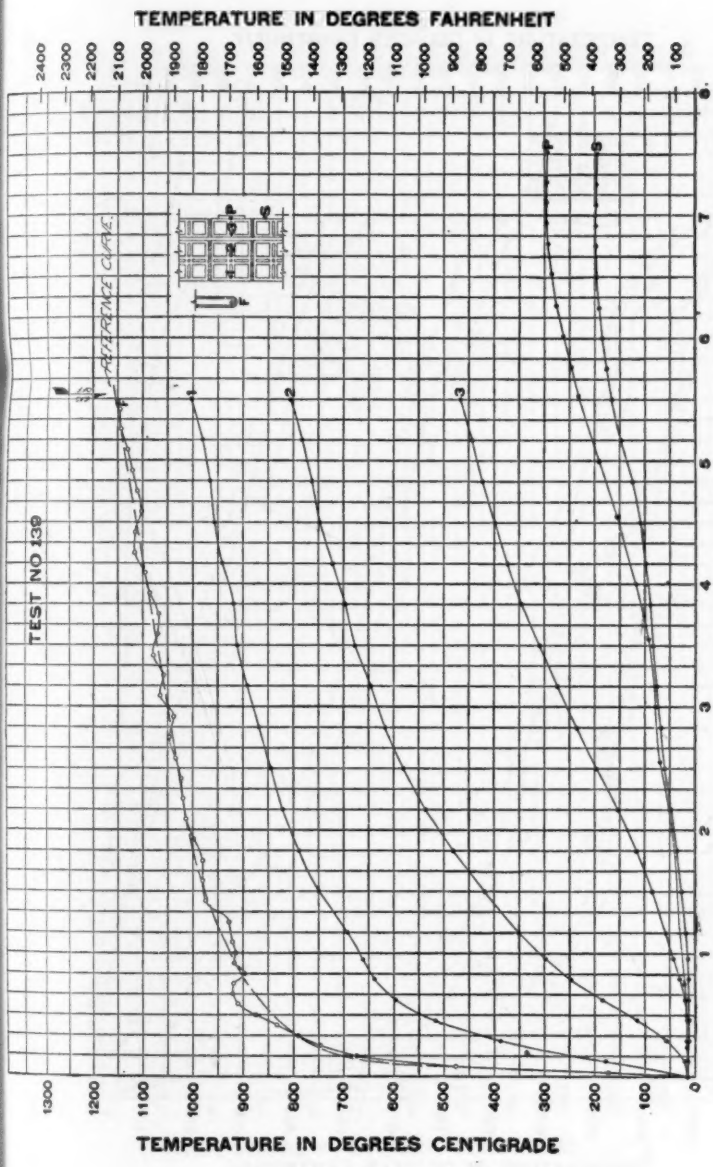


FIG. 160.—*Furnace and wall temperatures, 12-inch unplastered wall of side construction cube fire clay tile, source f, test No. 139*

FIG. 159.—*Furnace and wall temperatures, 12-inch unplastered wall of side construction H-shaped fire clay tile, source f, thirteen plaster bats, side test No. 138*

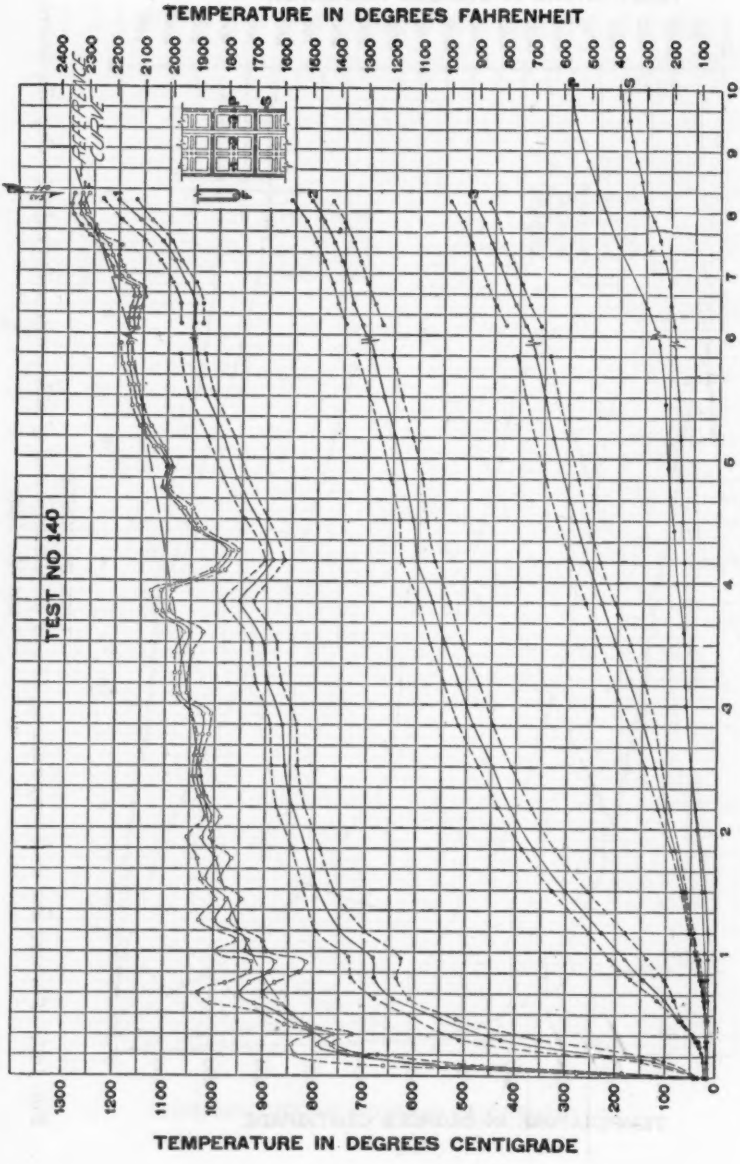


FIG. 161.—*Furnace and wall temperatures, 12-inch wall of side construction cube fire clay tile, source f, gypsum plaster both sides, test No. 140*

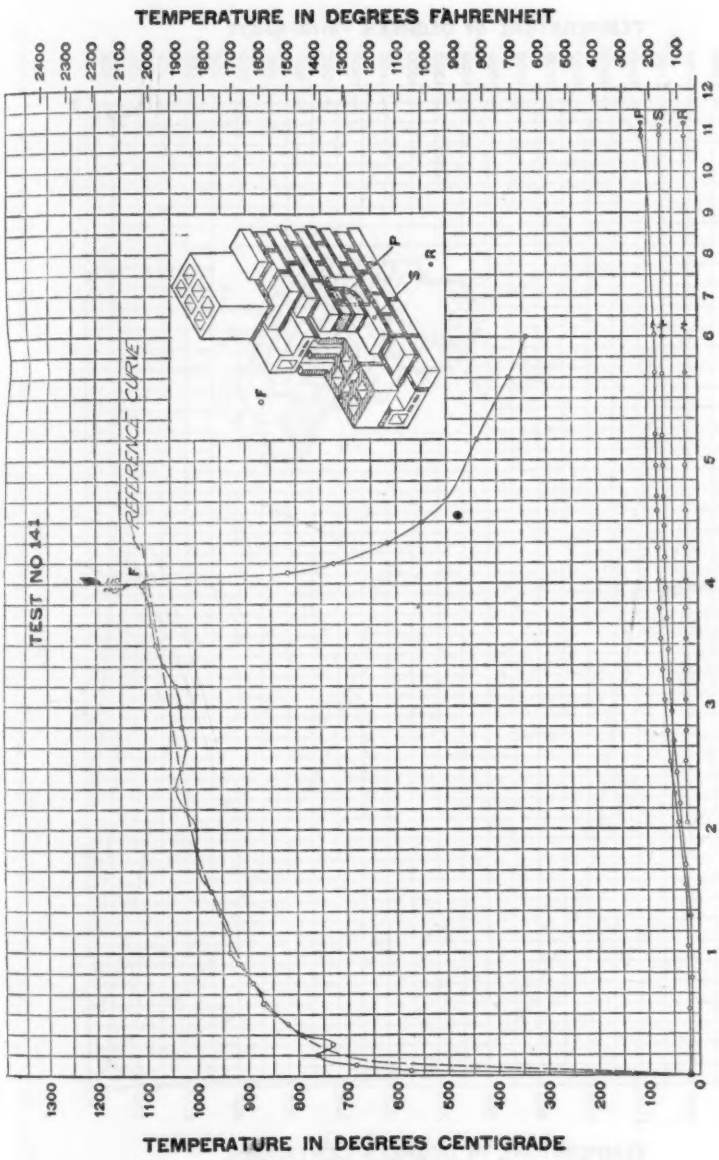


FIG. 162.—*Furnace and wall temperatures, brick-faced 12-inch unplastered wall backed with "header backer" fire clay tile, source p, test No. 141*

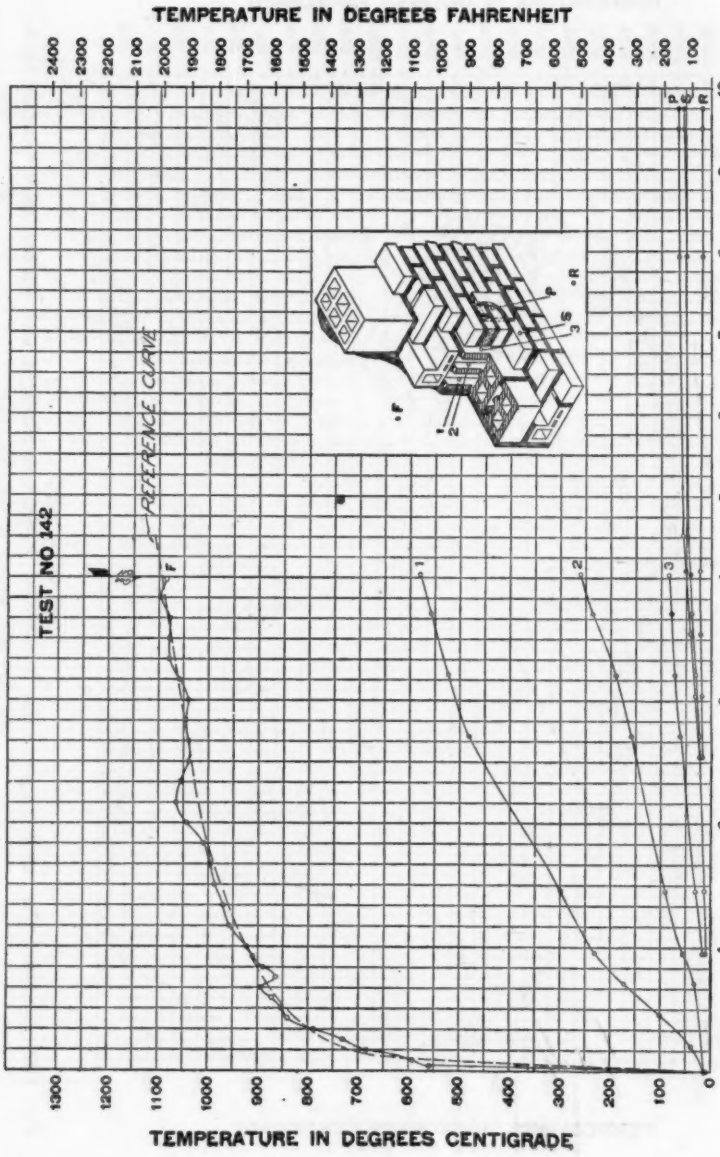


FIG. 163.—*Furnace and wall temperatures, brick-faced 12-inch wall of "header backer" fire clay tile, source P, gypsum plaster fire side, test No. 142*

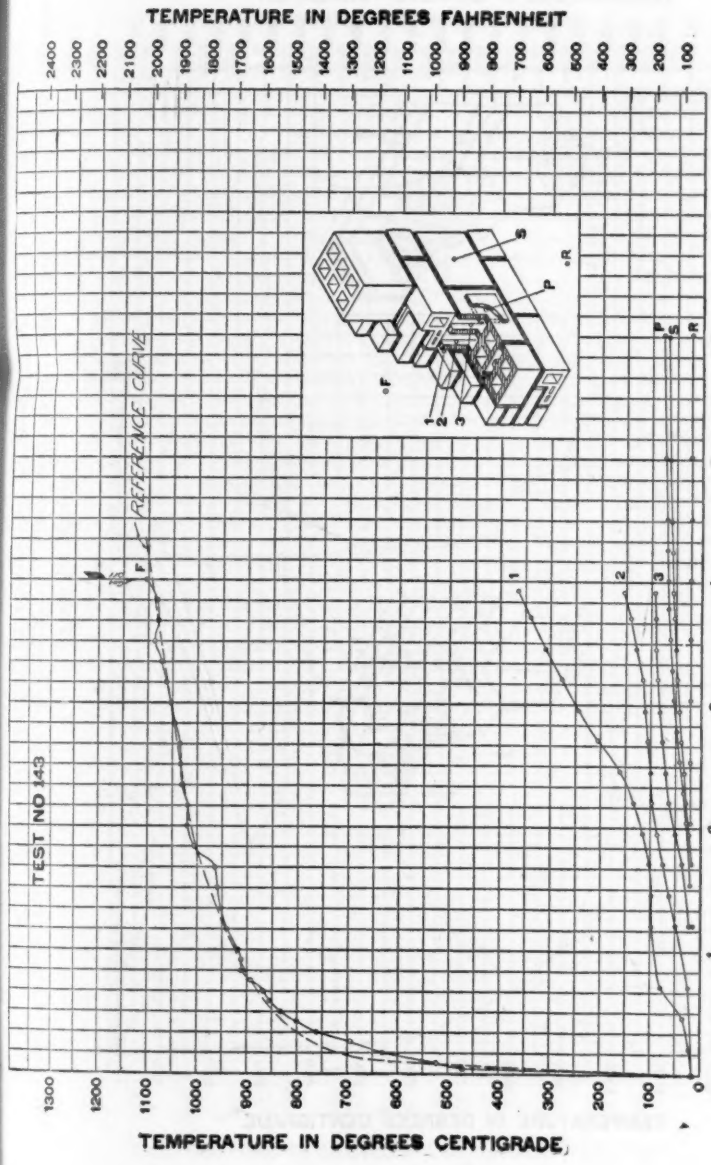


FIG. 164.—*Furnace and wall temperatures, brick-faced 12-inch unplastered wall of "header backer" fire clay tile, source p, test No. 143*

FIG. 163.—*Furnace and wall temperatures, brick-faced 12-inch wall of "header backer" fire clay tile, source p, gypsum plaster fire side, test No. 142*

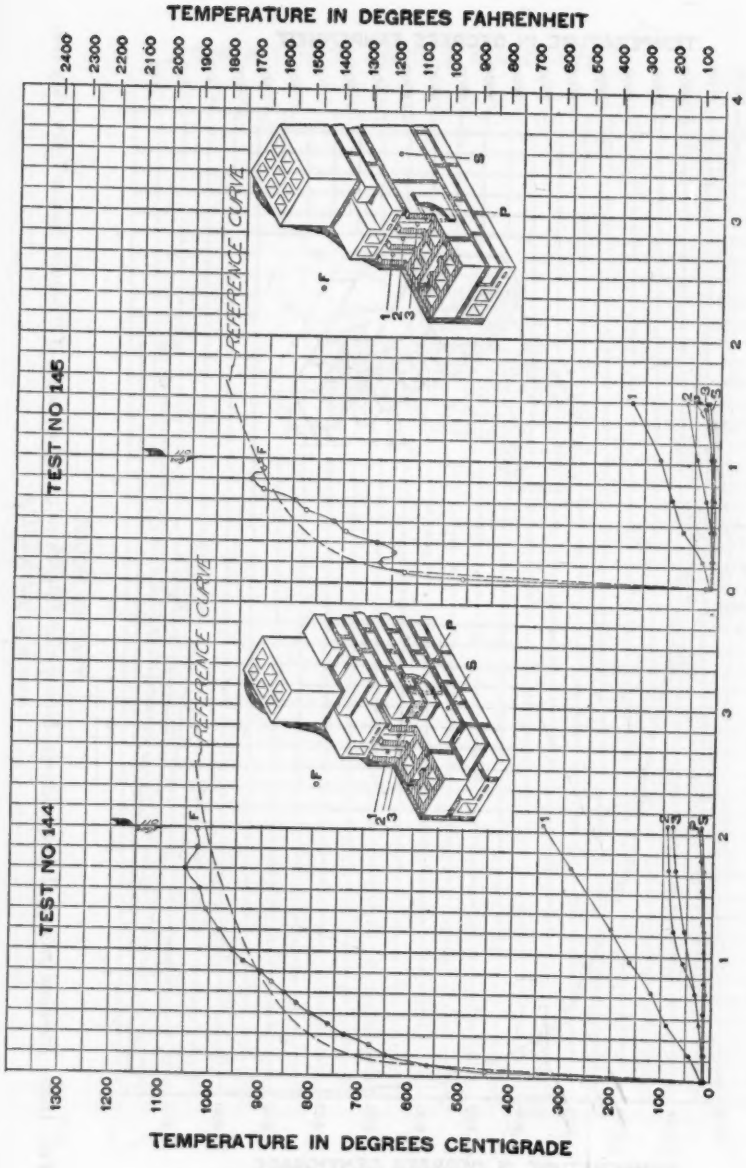


FIG. 165.—*Furnace and wall temperatures, brick-faced 12-inch wall backed with "header backer" fire clay tile, source p, gypsum plaster fire side, test No. 144; 12-inch wall of "header backer" fire clay tile, source p, gypsum plaster fire side, test No. 145*

source p, gypsum plaster fire side, test No. 144; 12-inch wall of "header backer" fire clay tile, source p, gypsum plaster fire side, test No. 145

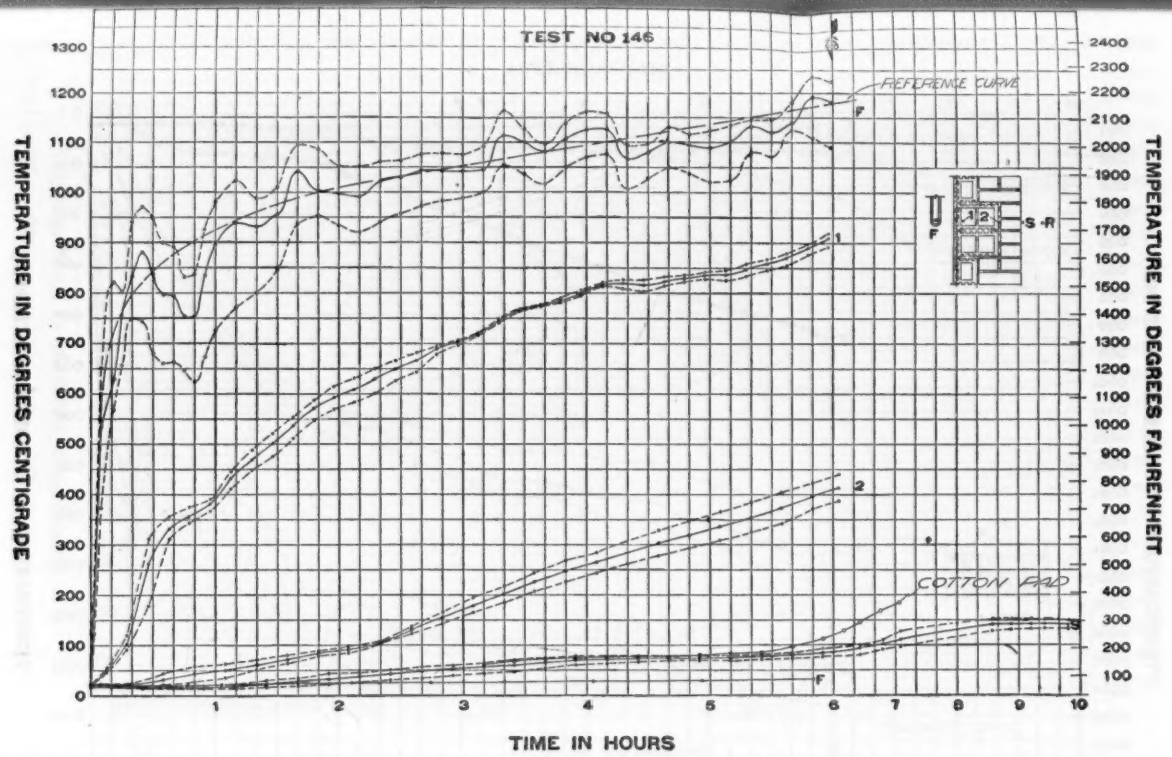


FIG. 166.—*Furnace and wall temperatures, brick-faced 12-inch wall backed with side construction 1-cell and 2-cell fire clay tile, source m, gypsum plaster fire side, test No. 146*

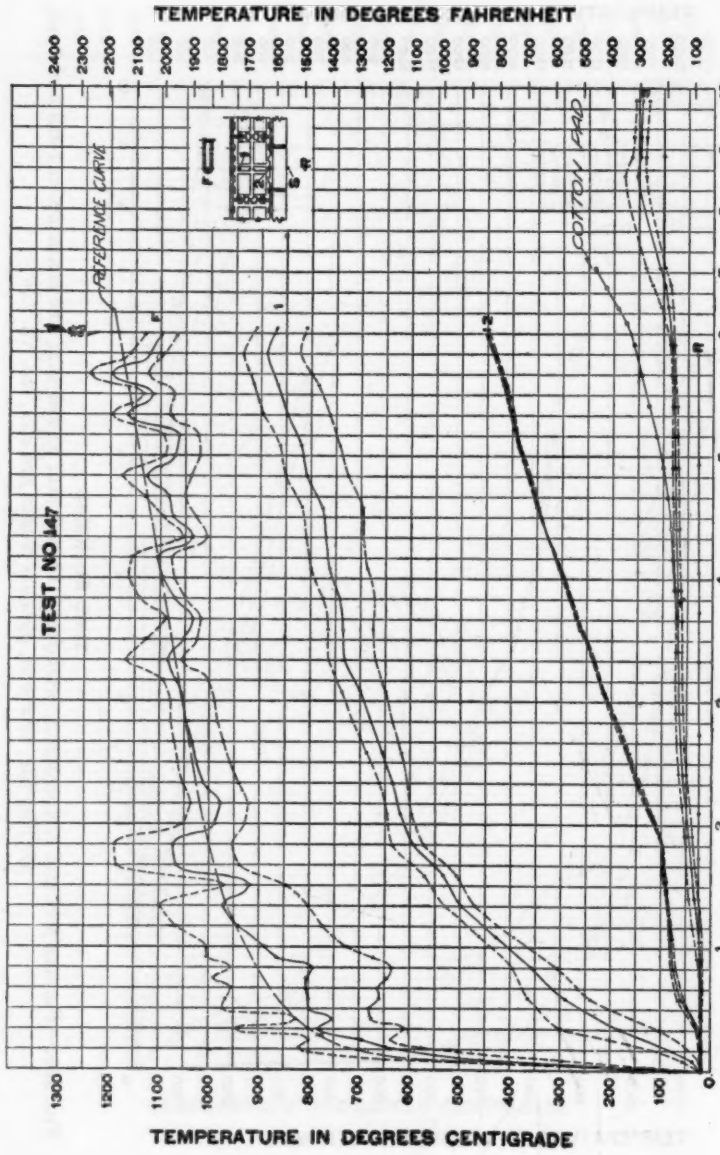
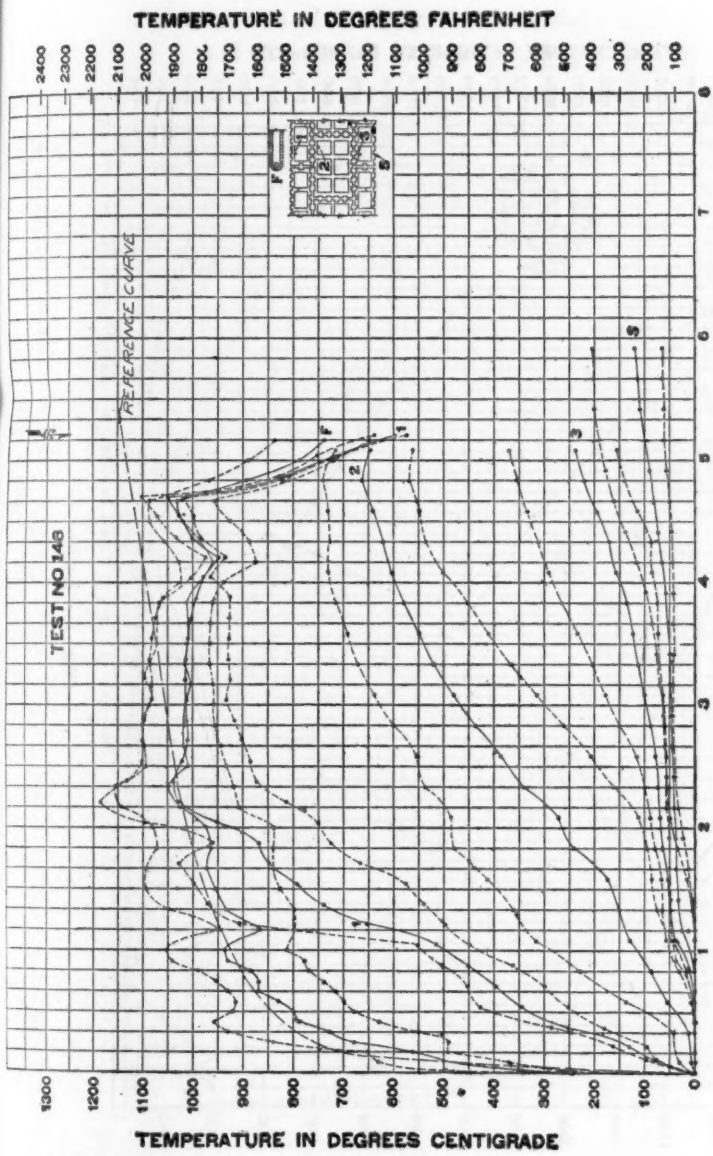


FIG. 167.—*Furnace and wall temperatures, brick-faced 12-inch wall backed with end construction "xx" fire clay tile, source m, gypsum plaster fire side, test No. 147*



108591°—28——20

FIG. 168.—*Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of end construction 6-cell and 3-cell shale tile, source d, test No. 148*

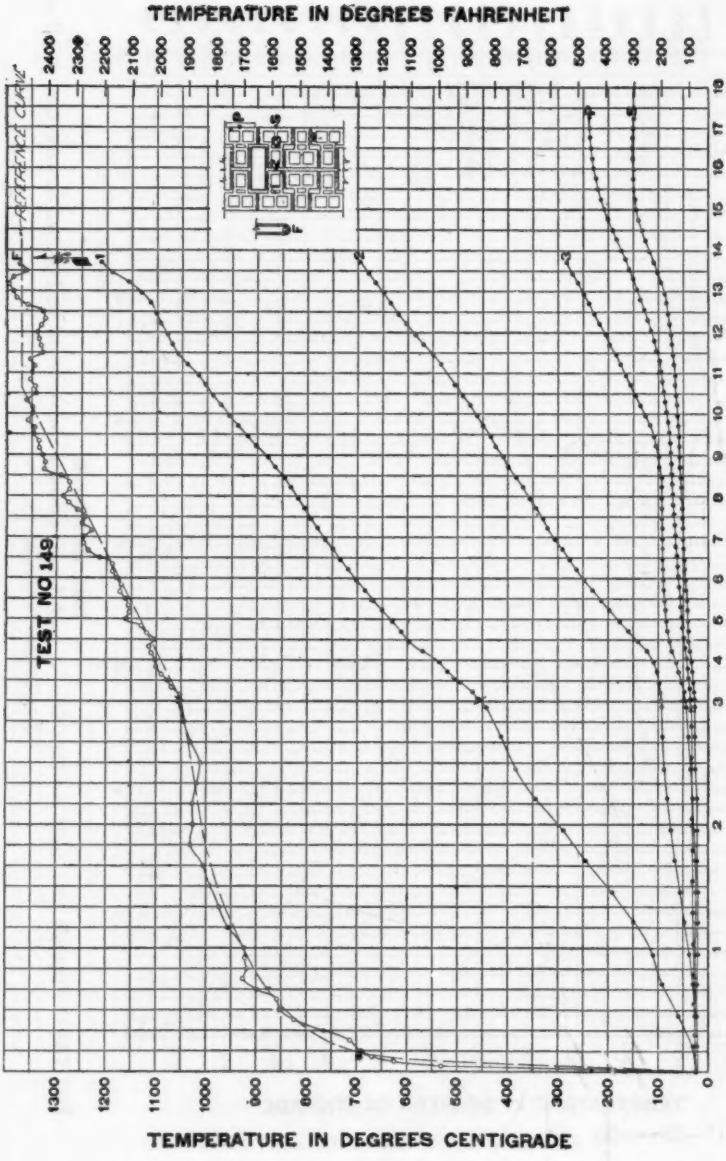


FIG. 169.—*Furnace and wall temperatures, 16-inch unplastered wall of side construction interlocking surface clay tile, source p–1, test No. 149*

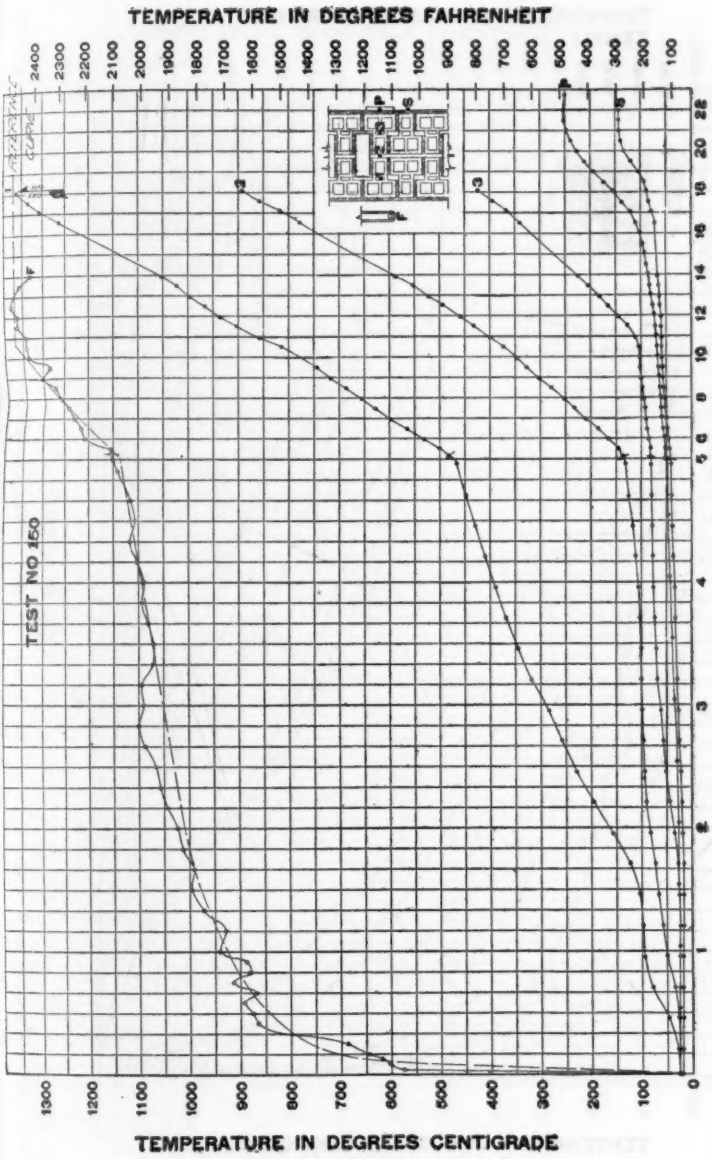


FIG. 170.—*Furnace and wall temperatures, 16-inch wall of side construction interlocking surface clay tile, source p–1, test No. 150*

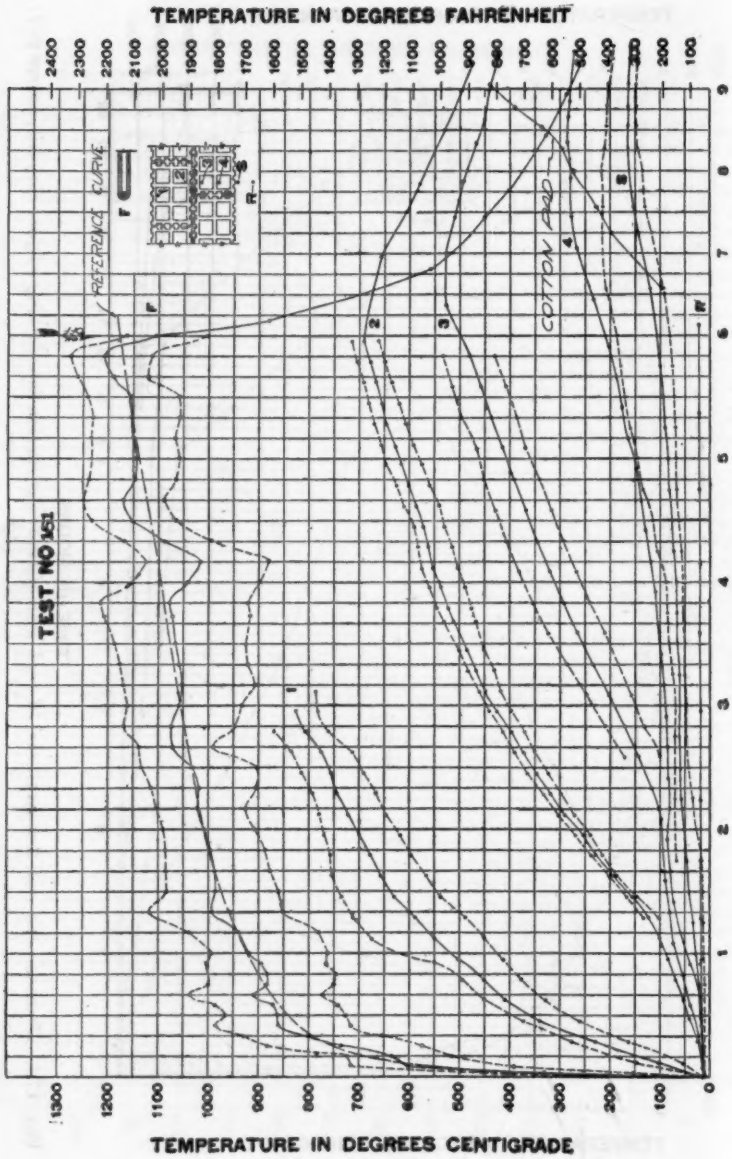


FIG. 171.—*Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of end construction 6-cell and 3-cell fire clay tile, source I, test No. 151*

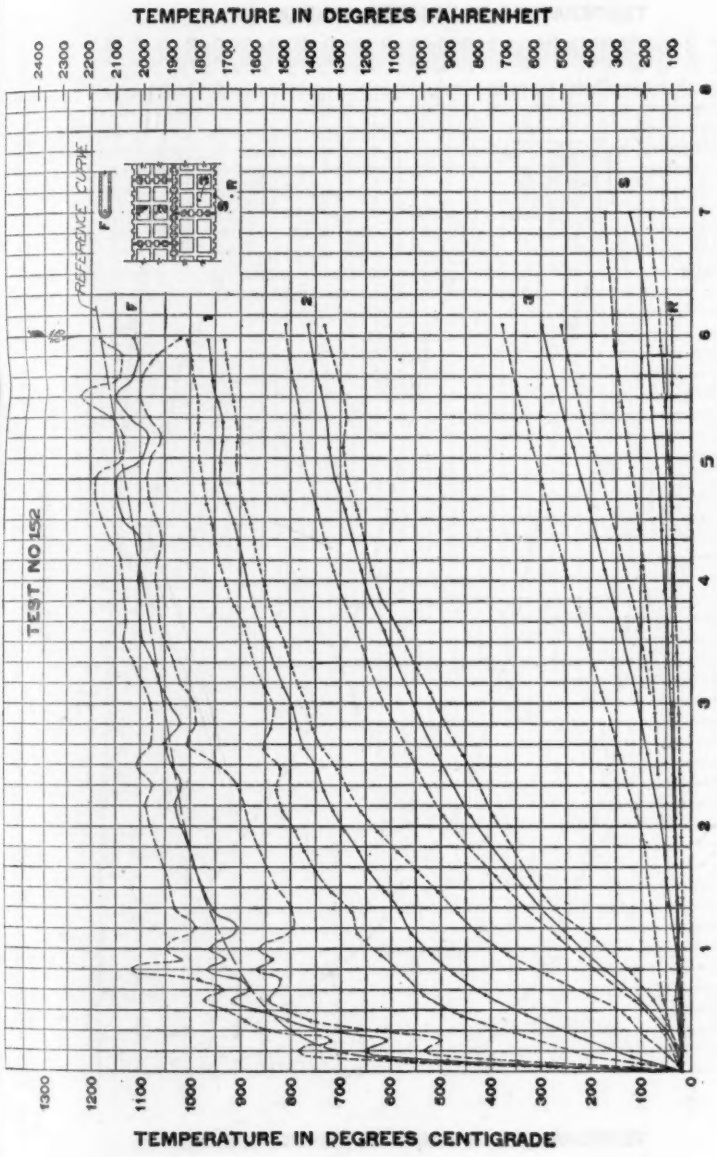


FIG. 172.—*Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of end construction 6-cell and 3-cell fire clay tile, source l, test No. 152*

FIG. 171.—*Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of end construction 6-cell and 3-cell fire clay tile, source l, test No. 161*

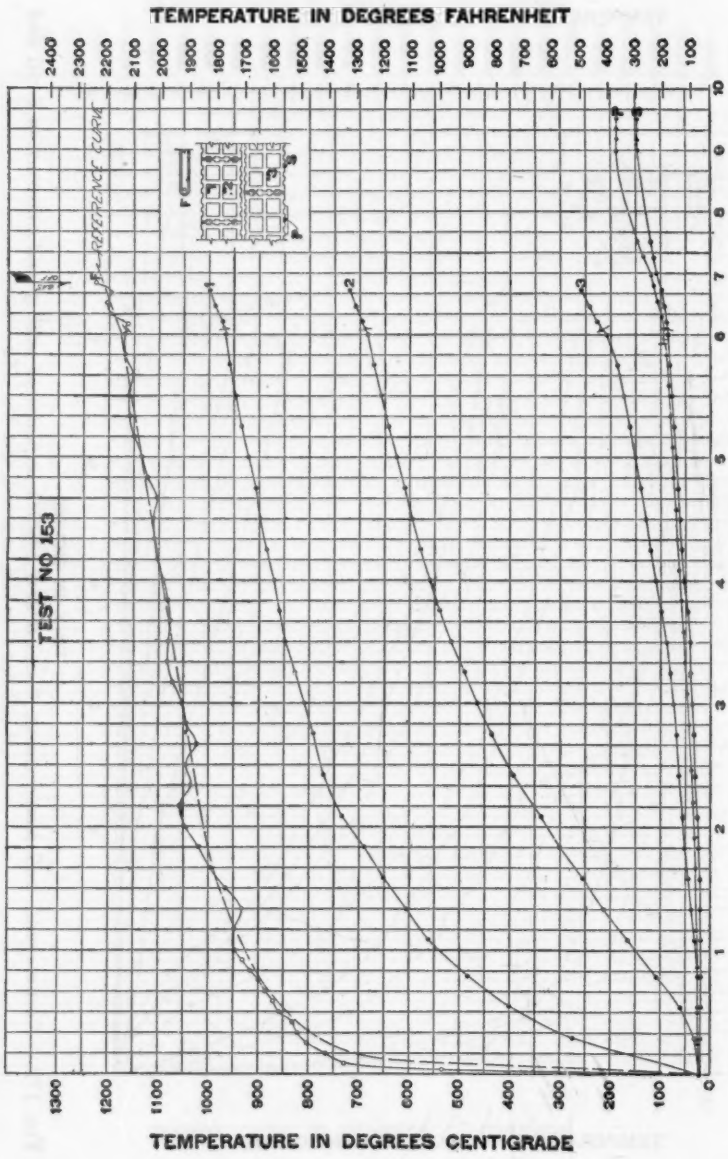


FIG. 173.—*Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of end construction 6-cell and 3-cell fire clay tile, source 1, test No. 153*

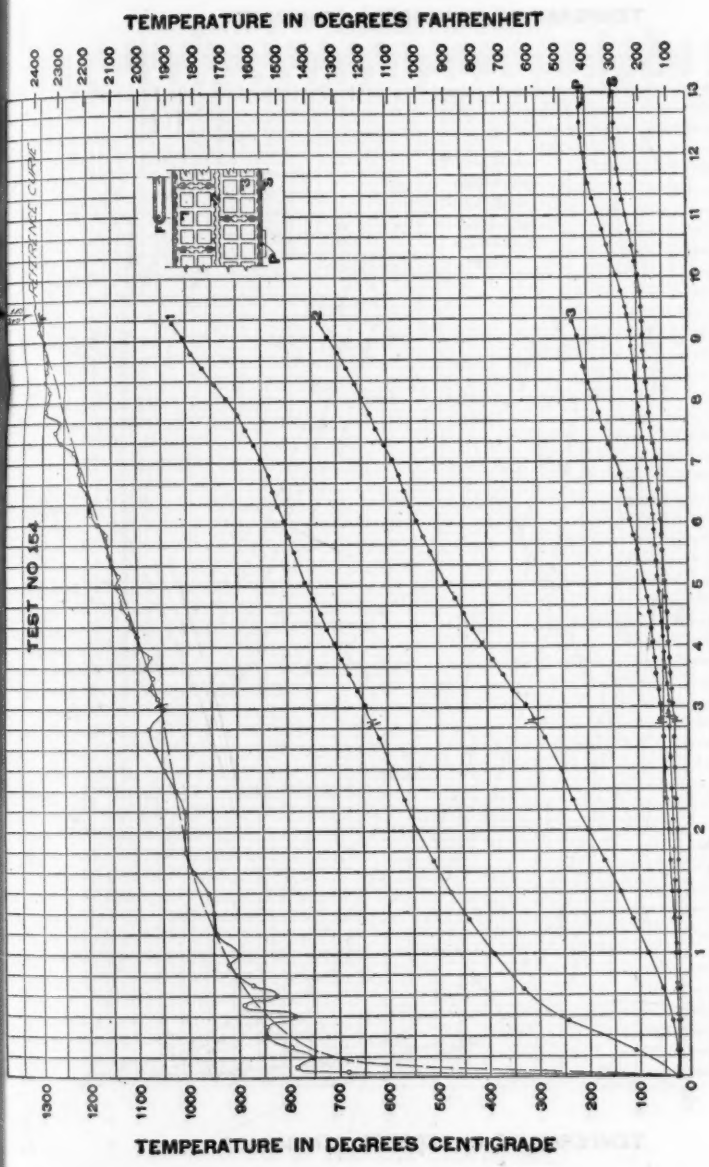


FIG. 174.—*Furnace and wall temperatures, 2 and 3 unit 16-inch wall of end construction 6-cell and 3-cell fire clay tile, source l, gypsum plaster both sides, test No. 154*

FIG. 173.—*Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of end construction 6-cell and 3-cell fire clay tile, source l, test No. 153*

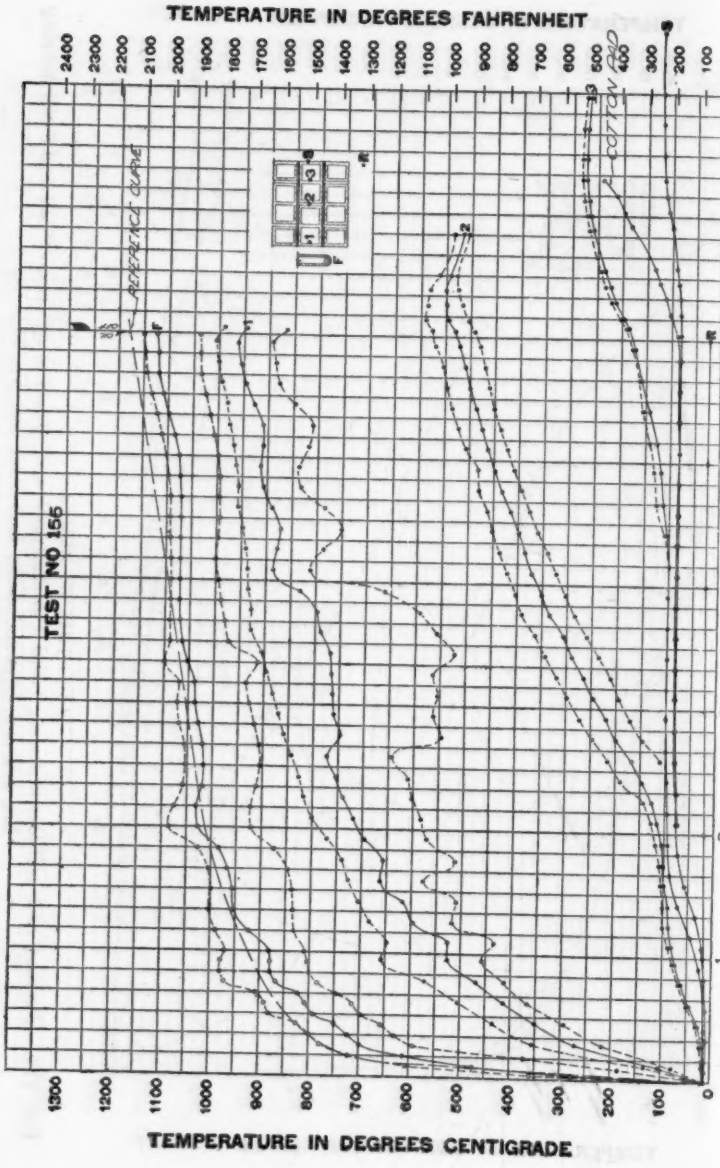


FIG. 175.—*Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of side construction 8 by 5 inch*
2-cell unit 8¾ by 5 inch 1-cell fire clay tile, source as test No. 152

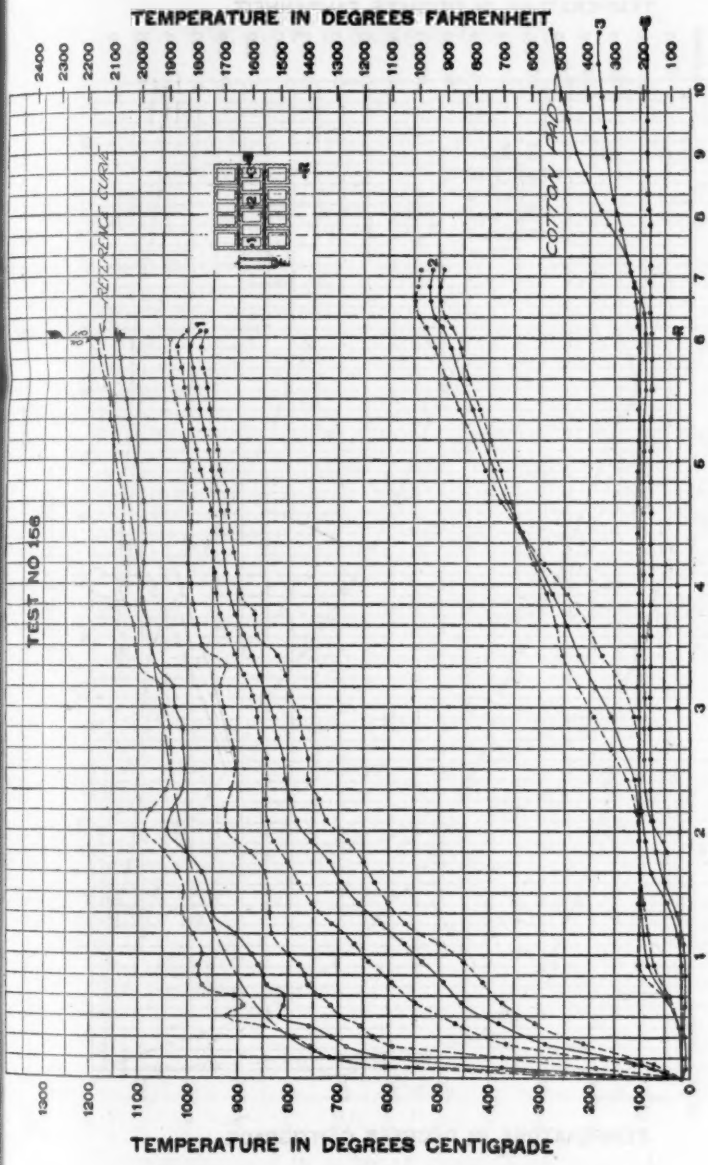


FIG. 176.—*Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of side construction 8 by 5 inch 3-cell and 3¾ by 5 inch 1-cell fire clay tile, source m, test No. 156*

FIG. 175.—*Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of side construction 8 by 5 inch 3-cell and 3¾ by 5 inch 1-cell fire clay tile, source m, test No. 166*

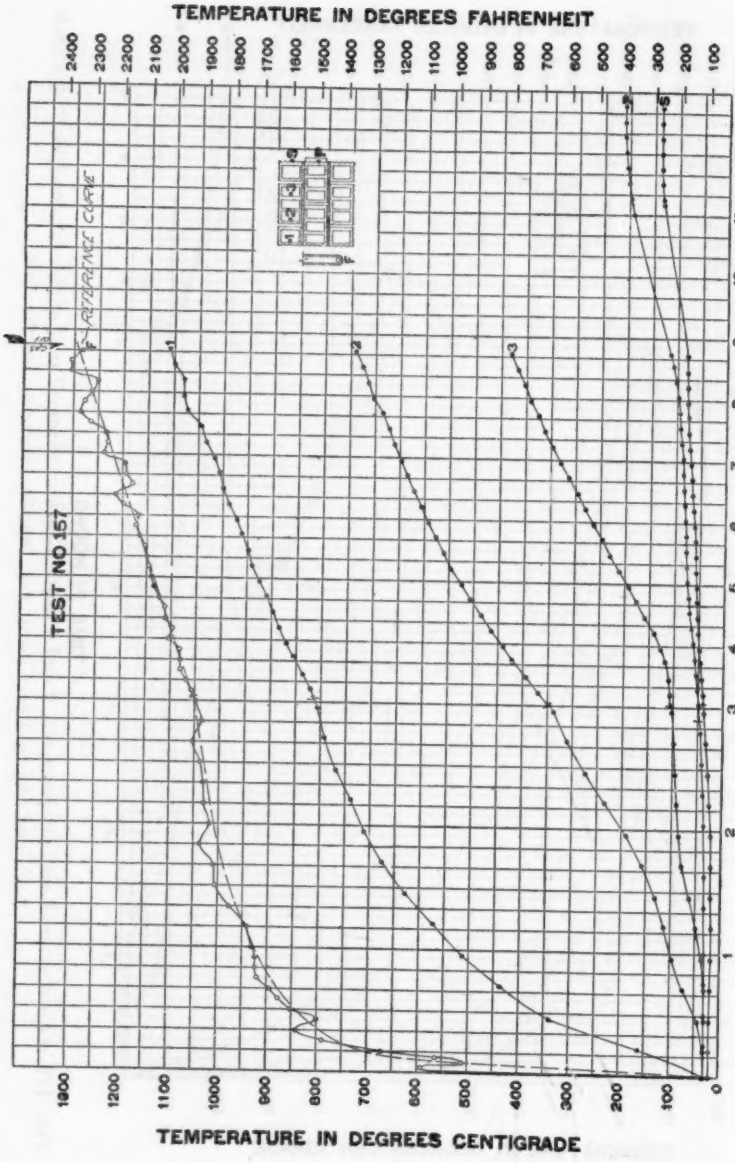


FIG. 177.—*Furnace and wall temperatures, 2 and 3 unit 10-inch unplastered wall of side construction 8 by 5 inch 3-cell and 3¾ by 5 inch 1-cell fire clay tile, source m, test No. 157*

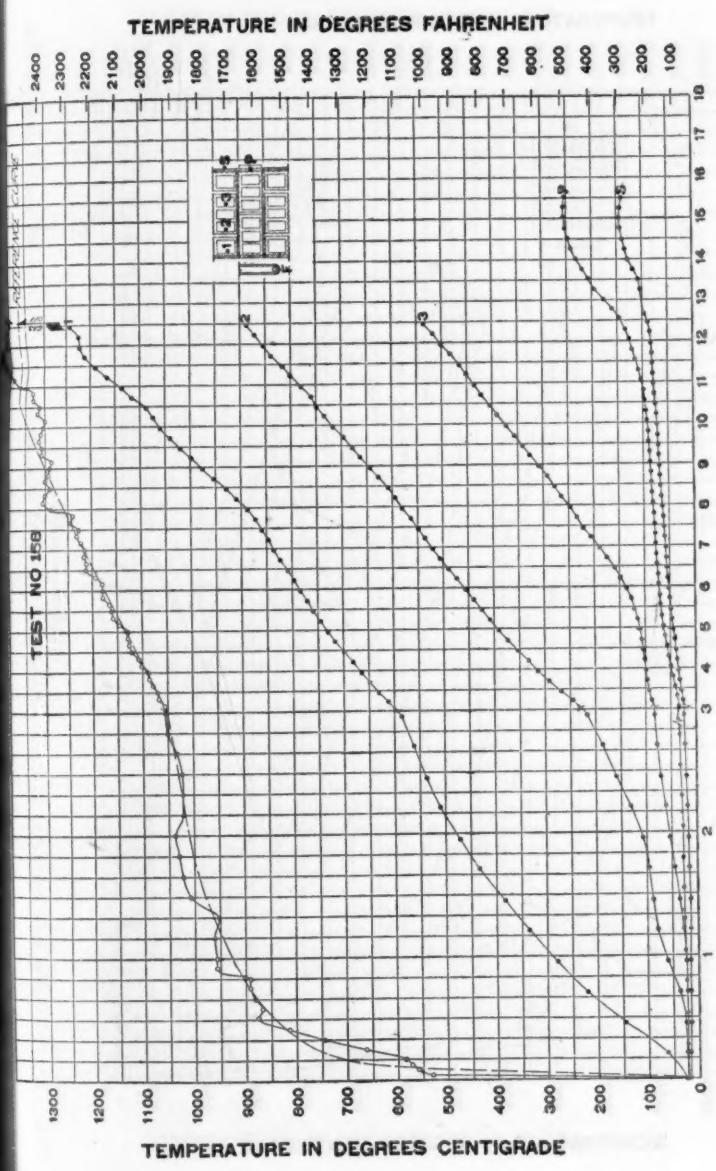


FIG. 178.—*Furnace and wall temperatures, 2 and 3 unit 16-inch wall of side construction 8 by 5 inch 3-cell and 3¾ by 5 inch 1-cell fire clay tile, source m, gypsum plaster both sides, test No. 158*

FIG. 177.—*Furnace and wall temperatures, 2 and 3 unit 16-inch unplastered wall of side construction 8 by 5 inch 3-cell and 3¾ by 5 inch 1-cell fire clay tile, source m, test No. 157*

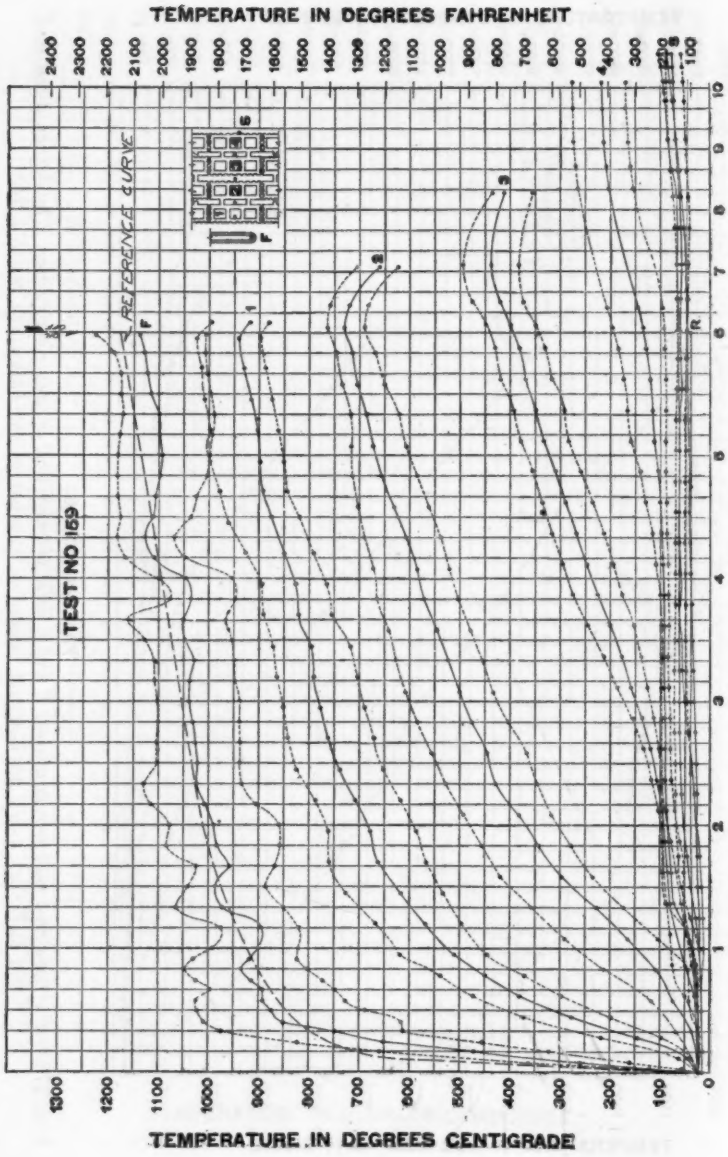


FIG. 179.—*Furnace and wall temperatures, 16-inch unplastered wall of side construction H-shaped fire clay tile, source 1, test No. 169*

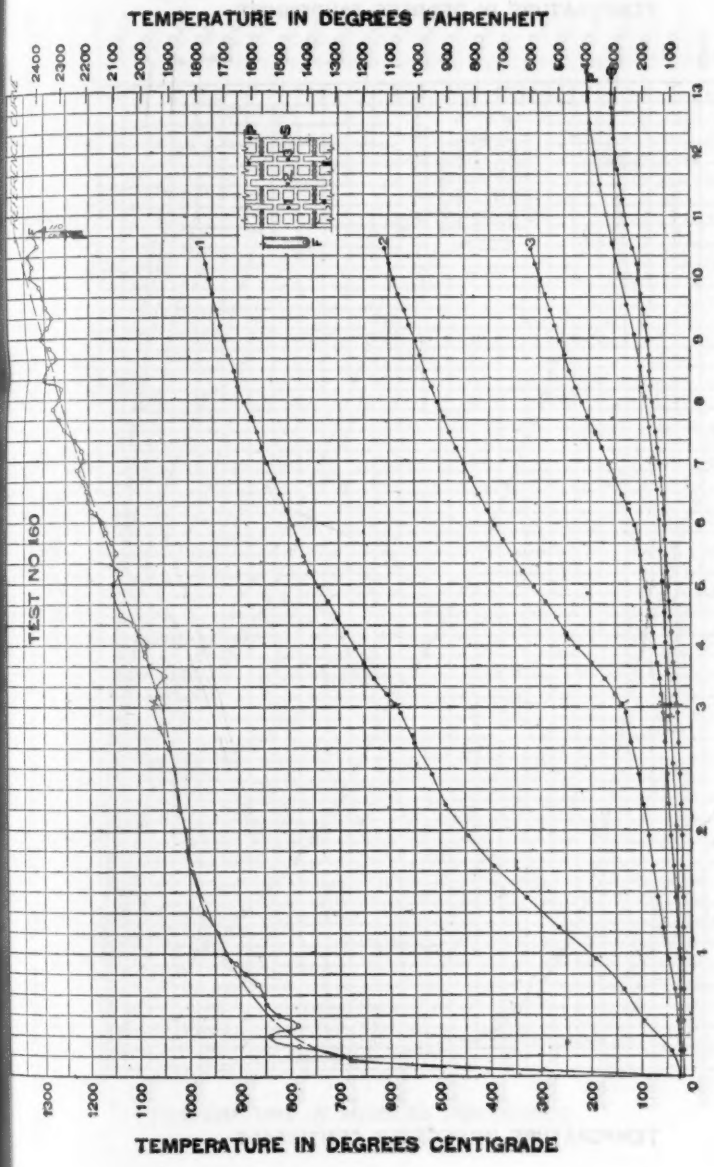


FIG. 180.—*Furnace and wall temperatures, 16-inch unplastered wall of side construction* H*-shaped fire clay tile, source l, test No. 160*

[Vol. 1

TIME IN HOURS

FIG. 179.—*Furnace and wall temperatures, 16-inch unplastered wall of side construction* H*-shaped fire clay tile, source l, test No. 159*

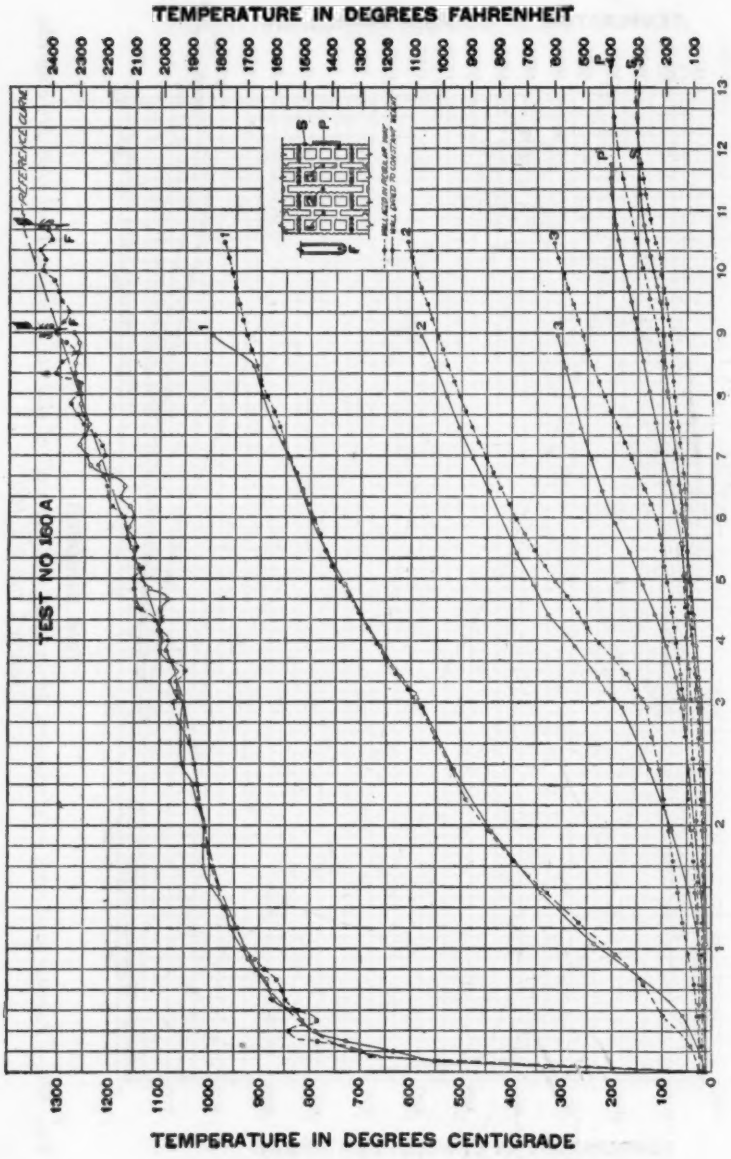


FIG. 181.—*Furnace and wall temperatures, 16-inch unplastered wall of side construction H-shaped fire clay tile, source L, dried to constant weight, test No. 150A*

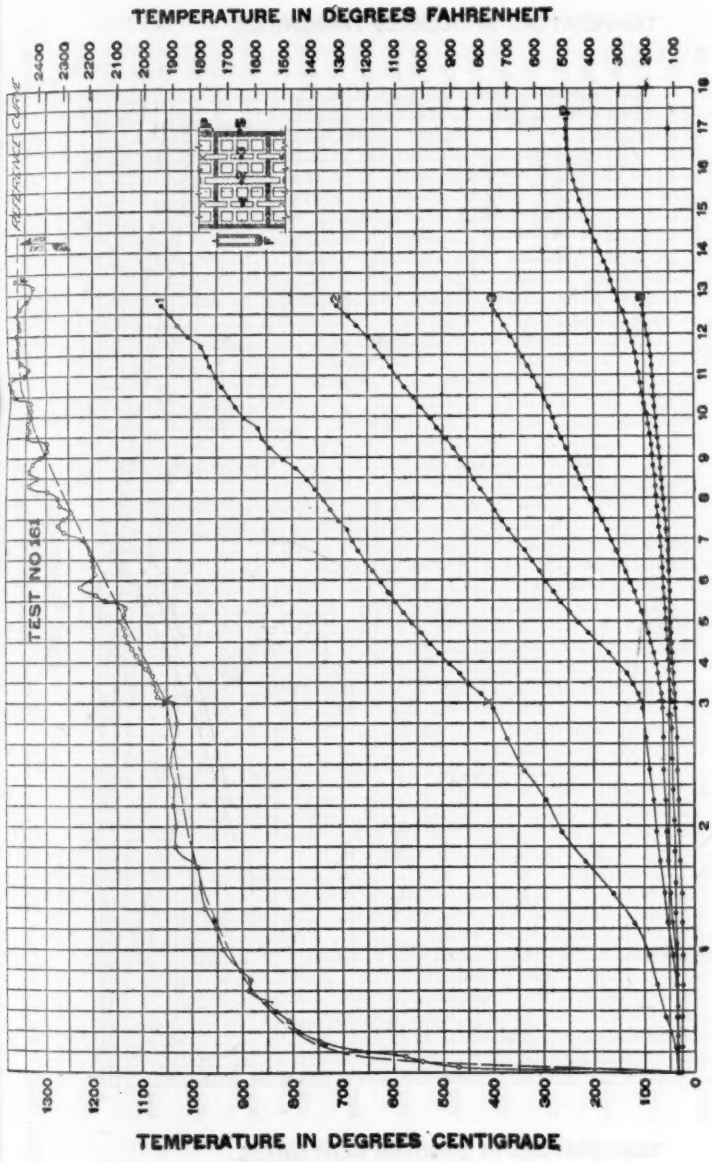


FIG. 182.—*Furnace and wall temperatures, 16-inch wall of side construction* H*-shaped fire clay tile, source l, gypsum plaster both sides, test No. 161*

FIG. 181.—*Furnace and wall temperatures, 16-inch unplastered wall of side construction* H*-shaped fire clay tile, source l, dried to constant weight, test No. 160A*

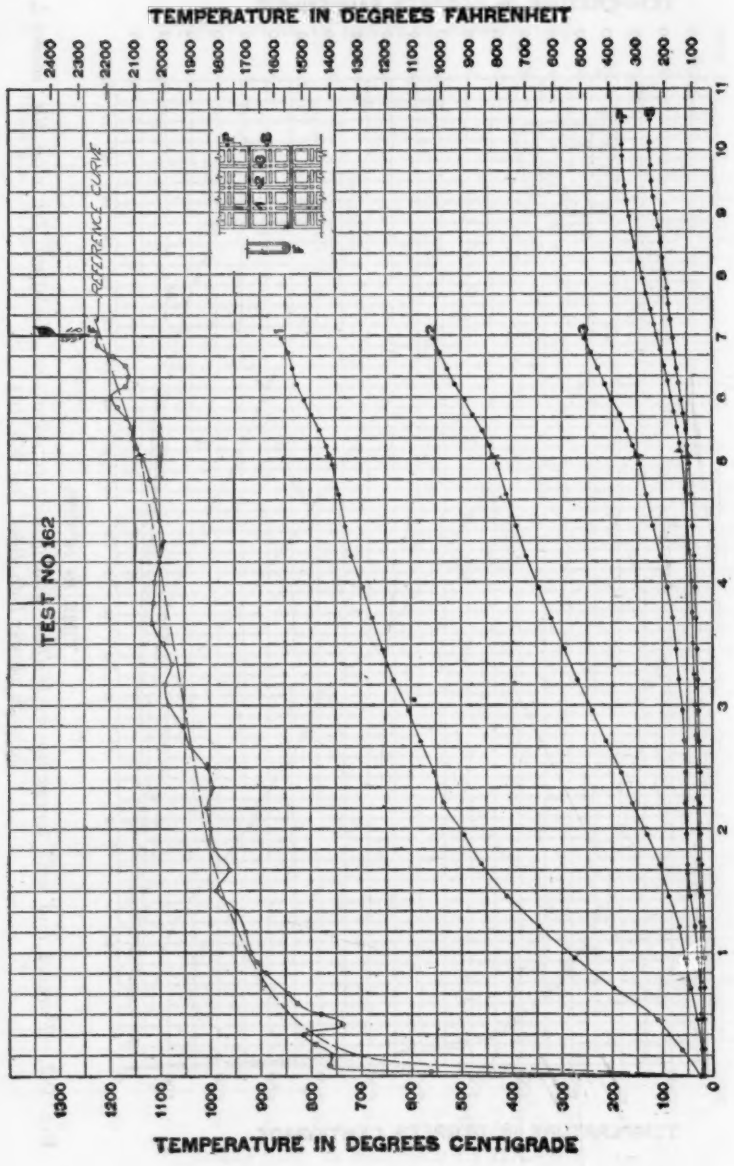


FIG. 183.—*Furnace and wall temperatures, 16-inch unplastered wall of side construction cube fire clay tile, source f. test No. 162*

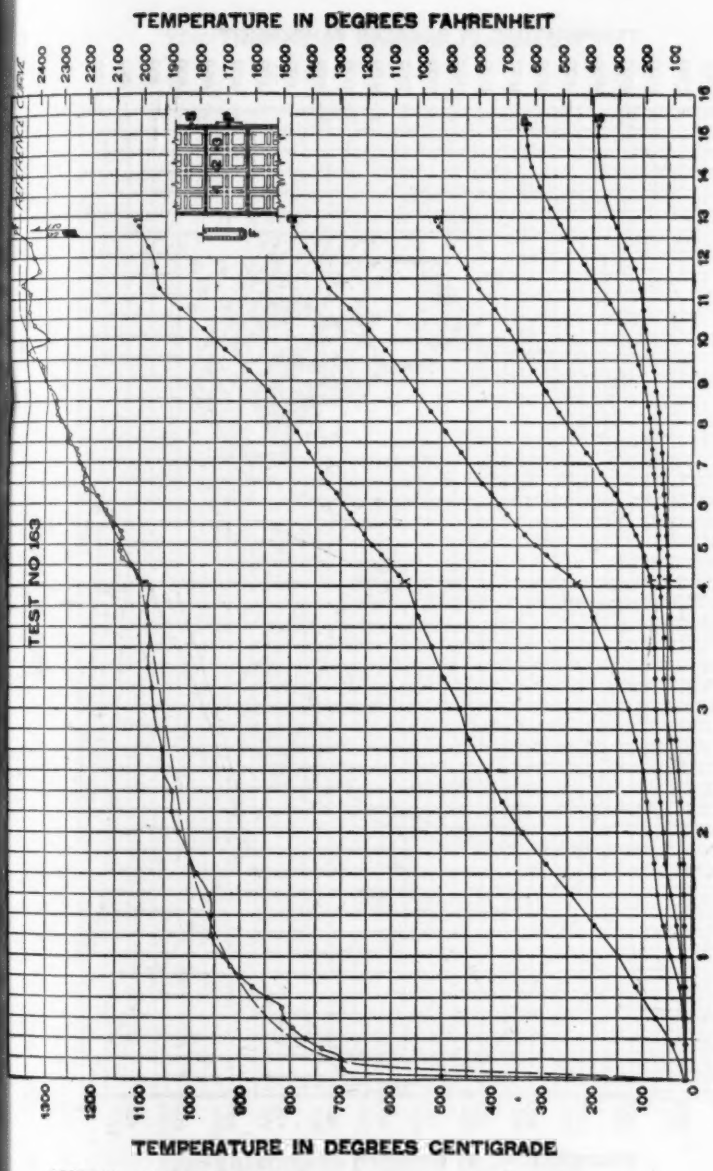


FIG. 184.—*Furnace and wall temperatures, 16-inch wall of side construction cube fire clay tile, source f, gypsum plaster both sides, test No. 163*

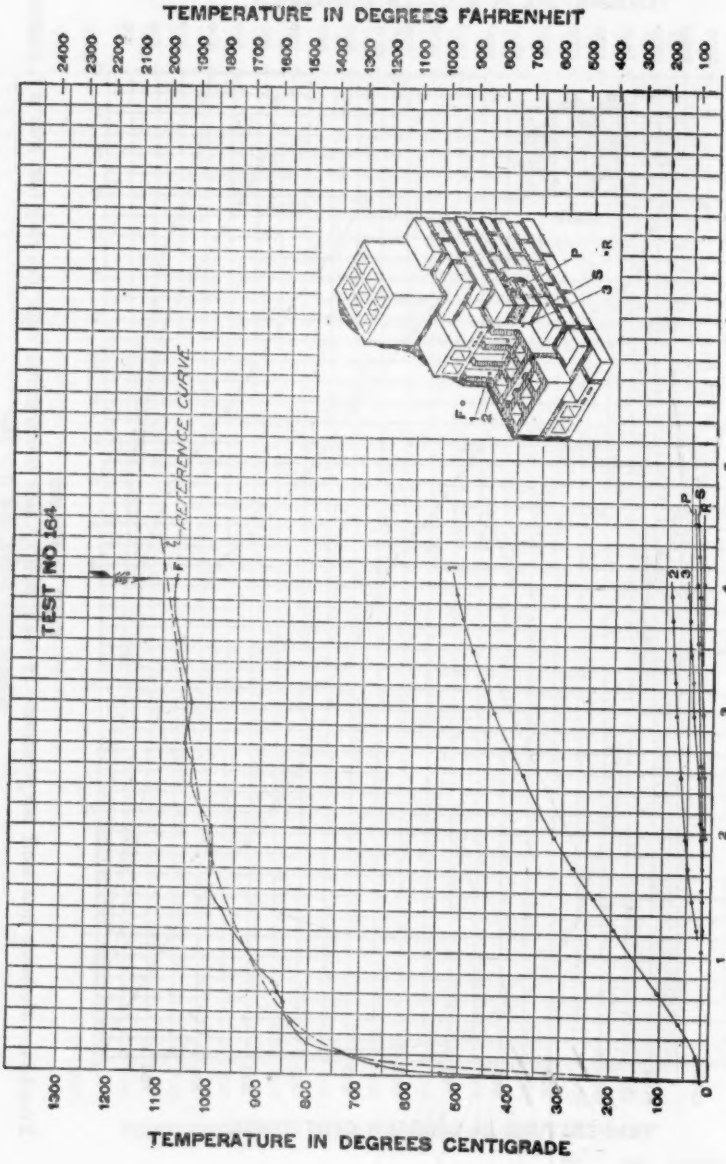


FIG. 185.—*Furnace and wall temperatures, 16-inch brick faced wall backed with "header backer" fire clay tile, source B, gypsum plaster fire side, test No. 164.*

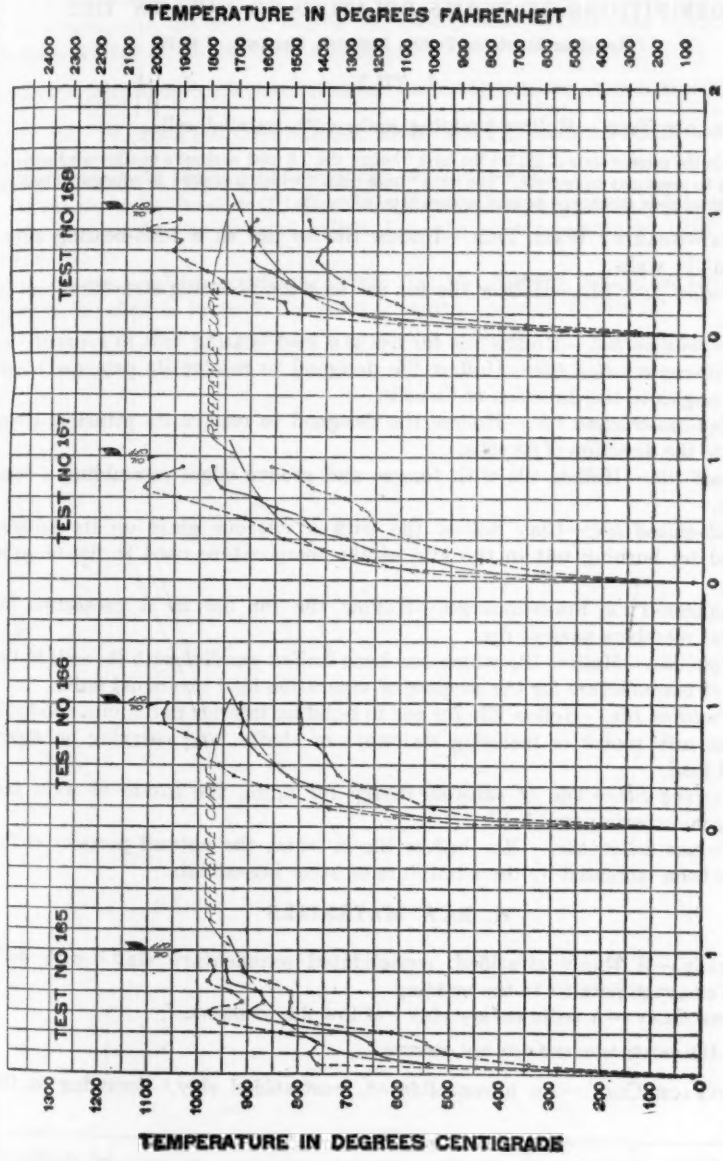


Fig. 186.—*Furnace temperatures, fire and water tests Nos. 165, 166, 167, and 168*

Fig. 185.—*Furnace and wall temperatures, 10-inch brick faced wall backed with "header backer" fire clay tile, source of gypsum plaster fire tests, test No. 164*

APPENDIX A

DEFINITIONS OF TERMS RELATING TO HOLLOW TILE

[American Society for Testing Materials, Standard: C 43-24]

I. TILE

1. HOLLOW TILE.—Hollow building units with parallel cells.

NOTE.—In the present state of the art the term "hollow tile," if used without a qualifying adjective, is understood to mean clay hollow tile. The term "terra cotta," which is applied to ornamental building units of burned clay, should not be used to designate hollow tile.

2. LOAD-BEARING WALL TILE.—Hollow tile for use as a load-bearing structural unit in walls.

(*a*) *Hollow floor tile.*—Hollow tile for use as a load-bearing structural unit in floors.

(*b*) *Foundation tile.*—Hollow tile for use as a load-bearing unit in foundations.

(*c*) *Side-construction tile.*—Hollow tile designed to receive its principal stress at right angles to the direction of its cells.

(*d*) *End-construction tile.*—Hollow tile designed to receive its principal stress parallel to the direction of its cells.

(*e*) *Book tile.*—Hollow tile with tongue and groove edges resembling a book in shape.

(*f*) *Salt-glazed tile.*—Clay hollow tile with a vitreous glaze on its surfaces produced by burning salt in the kiln at the temperature used in finishing the burning.

3. HOLLOW-TILE FIREPROOFING.—Hollow tile for use as a protection for structural members against fire.

(*a*) *Split tile.*—Hollow tile which has been knifed parallel with its cells in the process of manufacture for the purpose of separation into two equal units.

(*b*) *Partition tile.*—Hollow tile for use in building interior partitions, subdividing areas into rooms or inclosing stairways or shafts, and carrying no superimposed load.

(*c*) *Furring tile.*—Tile of suitable design for lining the inside of walls and carrying no superimposed load.

(*d*) *Porous hollow tile.*—Clay hollow tile in which the natural porosity of the clay has been increased by the admixture of other ingredients.

II. RAW MATERIALS

4. SHALE.—A thinly stratified, consolidated sedimentary clay [1] with well-marked cleavage parallel to the bedding.

5. FIRE CLAY.—A sedimentary clay [1] of low flux content.

NOTE.—It is usually associated with coal measures.

6. SURFACE CLAY.—An unconsolidated, unstratified clay,[1] occurring on the surface.

---

[1] The definitions for the terms "surface clay," "fire clay," and "shale" are based upon the following definition for "clay":

CLAY.—An earthy or stony mineral aggregate consisting essentially of hydrous silicates of alumina plastic when sufficiently pulverized and wetted, rigid when dry, and vitreous when burned at a sufficiently high temperature.

III. DESIGNATION OF DIMENSIONS

7. LENGTH.—In case of hollow tile, that dimension measured between its cut ends.

8. THICKNESS.—In the case of hollow tile, that dimension designed to lie at right angles to the face of the wall, floor, or other member in which it is used.

9. WIDTH.—In the case of hollow tile, that dimension measured at right angles to the direction of its thickness and length.

NOTE.—In practice, the first dimension given represents thickness; the second, width; the third, length.

IV. PARTS, OPENINGS, AND SURFACE FEATURES

10. SHELL.—In the case of hollow tile, the outer walls.

11. WEBS.—In the case of hollow tile, the partitions dividing it into cells.

12. CELLS.—In the case of hollow tile, the openings parallel with its shell and webs.

13. SCORING.—In the case of hollow tile, the grooves formed in the exterior faces of the shell to increase the bond of mortar, plaster, or stucco.

APPENDIX B

STANDARD SPECIFICATIONS AND TESTS FOR HOLLOW BURNED-CLAY LOAD-BEARING WALL TILE

[AMERICAN SOCIETY FOR TESTING MATERIALS, SERIAL DESIGNATION: C 34-26.]

SPECIFICATIONS

1. These specifications apply to hollow load-bearing wall tile made from surface clay, shale, fire clay, or admixtures thereof.

I. CLASSIFICATION

2. (*a*) According to the results of physical tests, tile shall be classified as hard, medium, and soft on the basis of the following strength and absorption requirements, both of which must be met for a given class:[1]

Class	Absorption (per cent)		Compressive strength, based on gross area (pounds per square inch)[1]			
			End construction		Side construction	
	Mean of 5 tests	Individual maximum	Mean of 5 tests	Individual minimum	Mean of 5 tests	Individual minimum
Hard	12 or less	15	2,000 or more	1,400	1,000 or more	700
Medium	16 or less	19	1,400 or more	1,000	700 or more	500
Soft	25 or less	28	1,000 or more	700	500 or more	350

[1] Gross area shall be taken as the total area inclosed by the outside dimensions of the unit taken in a direction perpendicular to that in which the load is carried.

(*b*) Where end-construction tile are used on the side, they shall meet the requirements of that construction, and *vice versa*.

(*c*) All tile shall be so designed that substantially the same masonry strength will be developed in all wall thicknesses for which they are to be used.

II. WEIGHTS

3. (*a*) The tile shall have the following dry weights, determined as hereinafter specified:

Size of unit (inches)	Number of cells	Standard weight	Size of unit (inches)	Number of cells	Standard weight
		Pounds			*Pounds*
3¾ by 12 by 12	3	20	8 by 5 by 12	2	16
6 by 12 by 12	6	30	8 by 5 by 12	3	16
8 by 12 by 12	6	36	8 by 5 by 12 (L-shaped)		16
10 by 12 by 12	6	42	8 by 6¼ by 12 (T-shaped)	4	16
12 by 12 by 12	6	48	8 by 7¾ by 12 (square)	6	24
12 by 12 by 12	9	52	8 by 10¼ by 12 (H-shaped)	7	32
3¾ by 5 by 12	1	9	8 by 8 by 8 (cube)	9	18

(*b*) A tolerance of 5 per cent will be allowed on the above standard weights.

[1] As different types of clay are used in the manufacture of tile, color can not be taken as indicative of classification.

III. DIMENSIONS

4. No dimension shall vary more than 3 per cent from the standard dimensions for any form of tile.

IV. WEATHERING RESISTANCE

5. All tile used in exterior work subjected to weathering conditions shall be able to withstand 100 alternate freezings and thawings. Tile classed as hard or medium by these specifications may be considered as meeting the weathering requirement, provided they are burned to the normal maturity for the given clay. Tile classed as soft shall be accepted as meeting the weathering requirement only on the basis of freezing tests.

V. FIRE RESISTANCE

6. The tile shall meet the following requirements as tested according to the Tentative Specifications for Fire Tests of Building Construction and Materials (Serial Designation: C 19–26T) of the American Society for Testing Materials [2] as they apply for bearing walls and partitions and to be acceptable shall develop the following resistance periods as tested unplastered:

Thickness of wall (inches)	Number of units in wall thickness	Number of cells in wall	Resistance period [1]
			Hours
8	1	2	1¼
8	1	3	2
12	1	3	3
12	2	3	4
12	2	4	5
16	2 or 3	4	6

[1] These are near the minimum values developed in tests. The average results will generally be higher. Plaster coatings ¾ inch thick applied on both sides and remaining in place throughout the fire test will increase the periods by 1 to 2 hours.

VI. WORKMANSHIP AND FINISH

7. All tile shall be well burned, reasonably free from laminations and from such cracks, blisters, surface roughness, and other defects as would interfere with the proper setting of the tile or impair the strength or permanence of the construction.

8. The exterior surface of all tile intended for plaster or stucco shall be scored in such a manner as to give good adhesion.

VII. MARKING

9. All tile shall bear the words "load bearing" and initials, name, or trademark of the manufacturer. These marks shall be indented on the exterior of the tile and shall be plainly legible.

VIII. INSPECTION AND REJECTION

10. Proper facilities shall be provided the purchaser for sampling and inspection either at the factory or at the site of the work, as may be specified in the contract. At least 10 days from the time of sampling shall be allowed for the completion of the test. The inspection shall be based on the requirements specified above. All tests shall be made in accordance with the methods hereinafter prescribed.

[2] Proc. Am. Soc. Testing Mats., **26**, Pt. I (1926); also 1926 Book of A. S. T. M. Tentative Standards.

11. Individual tile shall be rejected for failure to meet the weight, size, or workmanship and finish requirements. In case of failure to meet the absorption and strength requirements for the class specified, the seller may sort the shipment, and new samples shall be selected by the purchaser from the retained lot and tested at the expense of the seller. In case the second set of samples fails to meet the test requirements, the entire lot shall be rejected.

12. Except as specified in section 11 and unless otherwise agreed, the expense of inspection and testing shall be borne by the purchaser.

TESTS

IX. SAMPLING

13. Samples of tile for testing shall be selected by the purchaser or by a competent representative authorized by him to do this work. In all cases the samples shall be representative of the whole lot of tile from which they are selected. Full-size tile shall be taken in all cases.

14. For the strength, absorption, and weight determinations, five individual tile shall be selected from each kiln or from each 100-ton lot. In no case shall less than five tile be taken. For the fire test the size of the test panel will govern the number of tile required. Samples for the freezing tests shall be taken from tile that have not been subjected to strength or fire tests.

15. Samples for the strength and absorption tests shall be selected at the factory or at the site of the work, as specified. If the fire or freezing tests are to be made, it shall be so specified at the time of placing the order, samples for fire tests being selected at the factory at least 45 days in advance of the time of filling the order and 90 days in advance for freezing tests.

16. All tile selected for test shall be plainly and permanently marked for reference by the testing operator.

X. WEIGHT DETERMINATIONS

17. The five tile, if not in kiln-dry condition, shall be dried to constant weight at a temperature of not less than 100° C. (212° F.) and be weighed separately. The scale shall be sensitive to within 0.5 per cent of the weight of the smallest unit.

XI. STRENGTH TESTS

18. Five full-size dry tile shall be used.

19. The speed of the moving head of the testing machine shall not be more than 0.05 inch per minute.

20. A spherical bearing block of proper design shall be placed on top of the test sample.

21. (*a*) Bearing surfaces of the test samples and portions adjoining them which are liable to absorb water from the plastic capping shall be coated with one coat of shellac and allowed to dry. A quantity of plastic mortar made of a mixture of 3 parts (by volume) of Portland cement and 1 part of unretarded gypsum (plaster of Paris), mixed with sufficient water to spread evenly, shall be placed on a plain surface, which has been coated with oil, and allowed to harden sufficiently to bear the weight of the tile. The surface to be capped shall be placed on this mortar, and, while holding the specimen so that its axis is at right angles to the capping surface, it shall be given a single firm pressure.

(*b*) The average thickness of the cap after the extruded plaster has been removed and the edges trued shall not be more than $\frac{1}{8}$ inch. Patching of caps after setting shall not be permitted. Imperfect caps shall be removed and replaced with new ones.

(*c*) Where time is not available for aging the cement-gypsum cap, a cap of neat gypsum may be used, although the resulting tile strength will generally be lower than with the cement-gypsum cap. Any other method of capping which produces equally satisfactory results may be used.

22. When the cement-gypsum cap is used, it shall age at least three days before the tile is tested. Where the neat gypsum cap is used, the tile may be tested as soon as the plaster has been well set, but not sooner than one hour after the sample has been capped.

23. All tile shall be tested in the position in which they are designed to be used.

XII. ABSORPTION TESTS

24. The samples shall consist of five tile or three representative pieces from each of these five tile. If small pieces are used, two shall be taken from the shell and one from an interior web, the weight of each piece to be not less than 227 grams (½ pound). The samples shall have had their rough edges or loose particles ground off and be free from cracks from the failure of the tile in compression, where taken from tile which have been subjected to strength tests.

25. Each piece shall be marked so that it may be identified at any time with the tile from which it was taken. Markings which do not cover more than 5 per cent of the total superficial area of the piece shall be used.

26. Preparatory to the absorption tests, all samples shall be dried to constant weight in a drier or oven at a temperature of not less than 100° C. (212° F.).

27. The balance used shall be sensitive to within 0.2 per cent of the weight of the smallest unit or piece tested.

28. After obtaining the dry weight of the samples, they shall be immersed in soft, distilled, or rain water, raised to the boiling point, and boiled continuously for one hour, and then allowed to cool in water to room temperature.

29. After saturation, the sample shall be removed from the water and allowed to drain for not more than one minute. The superficial water shall be removed with a damp cloth, after which they shall be weighed immediately.

30. The test results shall be calculated as percentages of the initial dry weight, carried to the nearest first decimal place. The results shall be reported separately for each tile, with the average for the five tile.

XIII. FREEZING TESTS

31. Where the freezing test is to be made, five separate representative tile shall be selected.

32. If not possible to use the whole tile, a piece consisting of a cell not less than 4 inches long shall be sawed from the tile. These pieces shall be saturated by immersion in cold water for at least 72 hours prior to starting the freezing.

33. Any practical method of obtaining alternate freezings and thawings may be used, the freezings to be always made with fully saturated samples and the time and temperature to be such as to insure full freezing and thawing throughout the specimen. The initial weighing and all weighings for loss shall be made on dry specimens.

34. The balance used shall be sensitive to within 0.1 per cent of the weight of the smallest unit or piece tested.

35. Failure under the freezing and thawing treatment shall be considered to be reached when—

(*a*) The samples show superficial disintegration or spalling with loss of weight of more than 5 per cent of the initial weight; or

(*b*) The samples are badly cracked; or

(*c*) The samples show evident loss of structural strength.

APPENDIX C

TENTATIVE SPECIFICATIONS FOR FIRE TESTS OF BUILDING CONSTRUCTION AND MATERIALS

[American Engineering Standards Committee, A 2–1926]

1. (*a*) The test methods are applicable to assemblies of masonry units and to composite assemblies of structural materials for buildings, including bearing and other walls and partitions, columns, girders, beams and slabs, and composite slab and beam assemblies for floors and roofs. They are also applicable to other assemblies and structural units which constitute permanent integral parts of a finished building.

(*b*) It is the intent that classifications shall register performance during the period of exposure and shall not be construed as having determined suitability for use after fire exposure.

I. CONTROL OF FIRE TESTS

2. The conduct of fire tests of materials and construction shall be controlled by the standard time-temperature curve shown in Figure 187. The points on the curve which determine its character are:

1,000° F. (approximately 538° C.)	at 5 minutes.
1,300° F. (approximately 704° C.)	at 10 minutes.
1,550° F. (approximately 843° C.)	at 30 minutes.
1,700° F. (approximately 927° C.)	at 1 hour.
1,850° F. (approximately 1,010° C.)	at 2 hours.
2,000° F. (approximately 1,093° C.)	at 4 hours.
2,300° F. (approximately 1,260° C.)	at 8 hours.

3. (*a*) The temperature fixed by the curve shall be deemed to be the average temperature obtained from the readings of several thermocouples (not less than three) symmetrically disposed and distributed to show the temperature near all parts of the sample, the thermocouples being inclosed in sealed porcelain tubes three-fourths inch in outside diameter and of one-eighth-inch wall thickness. The exposed length of the porcelain tube and couple in the furnace chamber shall be not less than 12 inches. Other types of protecting tubes or pyrometers may be used that under test conditions give the same indications as the above standard within the limit of accuracy that applies for furnace-temperature measurements. For greater difference of design and size, the time-temperature curve followed shall be modified to give an exposure equal to that obtained by using the standard pyrometer and curve above described.

(*b*) The temperatures shall be read at intervals not exceeding five minutes during the first hour, and thereafter the intervals may be increased to not more than 15 minutes.

(*c*) The accuracy of the furnace control shall be such that the area under the time-temperature curve, obtained by averaging the results from the pyrometer readings, is within 15 per cent of the corresponding area under the standard time-temperature curve shown in Figure 187 for fire tests of one hour or less duration; within 10 per cent for those over one hour and not more than two hours; and within 5 per cent for tests exceeding two hours in duration.

4. (*a*) Temperatures at unexposed surfaces shall be measured with thermocouples or thermometers [1] placed under oven-dry asbestos fire-felt pads 6 inches square, 0.4 inch thick, and weighing not less than 1.0 lb./ft.^{2} nor more than 1.4 lbs./ft.^{2} The wire leads of the thermocouple or the stem of the thermometer shall have an immersion under the pad and be in contact with the unexposed surface for not less than 3½ inches. The hot junction of the thermocouple or the bulb of the thermometer shall be placed approximately under the center of the pad. The outside diameter of protecting tubes of glass, clay, or porcelain, and of thermometer stems, shall not be more than five-sixteenths inch. The pad shall be held firmly against the surface and shall fit closely about the thermocouples or thermometer stems. Thermometers shall be of the partial-immersion type, with a length of stem, between the end of the bulb and the immersion mark, of 3 inches. The wires for the thermocouple in the length covered by the pad shall not be heavier than No. 18 B. & S. gauge (0.04 inch) and shall be electrically insulated with heat and moisture resistant coatings.

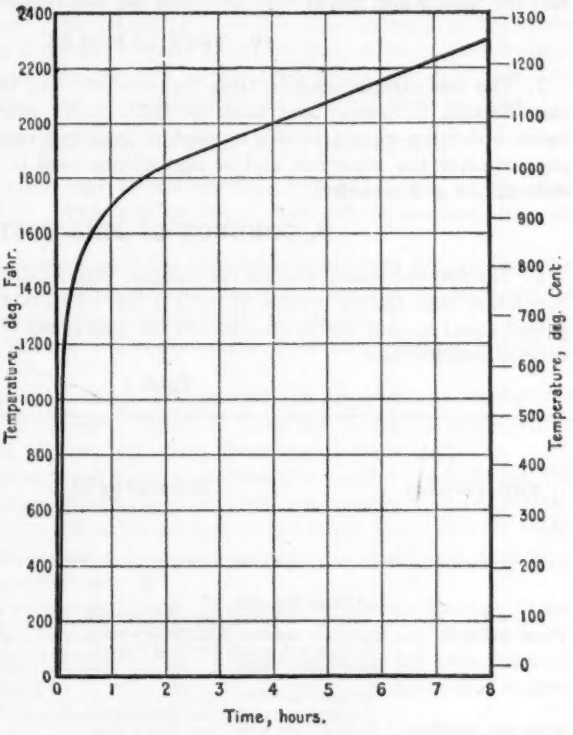


FIG. 187.—*Standard time-temperature furnace control curve*

(*b*) The temperature readings shall be taken at not less than 5 points on the surface, 1 of which shall be approximately at the center, and 4 at approximately the centers of the quarter sections. If additional points are used, they shall be symmetrically disposed about the center, with no location nearer than one and one-half times the thickness of the construction, or nearer than 12 inches, to the edges. None shall be located opposite or on top of beams, girders, pilasters, or other structural members.

(*c*) Temperature readings shall be taken at intervals not exceeding 15 minutes until a reading exceeding 212° F. (100° C.) has been obtained at any one point. Thereafter the readings may be taken more frequently at the discretion of the testing body, but the intervals need not be less than five minutes.

(*d*) Where the conditions of acceptance place a limitation on the rise of temperature of the unexposed surface, the temperature-end point of the fire-endurance period shall be determined by the average of the measurements taken at individual points; excepting that if a temperature rise 30 per cent in excess of the specified limit occurs at any one of these points, the remainder shall be ignored and the fire-endurance period judged as ended.

[1] Under certain conditions it may be unsafe or impracticable to use thermometers.

II. CLASSIFICATION AS DETERMINED BY TEST

5. Results shall be reported in accordance with the performance in the tests prescribed in these specifications. They shall be expressed in time periods of resistance, as, for example, four-hour, one-half hour, etc.

III. TEST STRUCTURES

6. (*a*) The test structure may be located at any place where all the necessary facilities for properly conducting the test are provided.

(*b*) Entire freedom is left to each investigator in the design of his test structure and the nature and use of fuel, provided the test requirements are met.

IV. TEST SAMPLES

7. The test sample shall be truly representative of the construction for which classification is desired and shall be built under conditions representative of those obtaining as practically applied in building construction. The physical properties of the materials and/or ingredients used in the test sample shall be determined and recorded.

V. CONDUCT OF FIRE TESTS

8. The fire-endurance test on the sample, with its applied load, if any, shall be continued until failure occurs, or until it has withstood the test conditions for a period equal to that herein specified in the conditions of acceptance for the given type of construction.

Table 1

Parts of structure	Resistance period	Water pressure at nozzle	Duration of application (per 100 sq. ft. exposed area)
		Lbs./in.²	*Minutes*
Floors and roofs	8 hours and over	45	6
	4 hours and over if less than 8 hours	45	5
	2 hours and over if less than 4 hours	45	2½
	1 hour and over if less than 2 hours	30	1½
	Less than 1 hour	30	1
Walls and partitions	8 hours and over	45	6
	4 hours and over if less than 8 hours	45	5
	2 hours and over if less than 4 hours	30	2½
	1 hour and over if less than 2 hours	30	1½
	Less than 1 hour	30	1

9. (*a*) Where required by the conditions of acceptance, a duplicate sample shall be subjected to a fire-exposure test for a period equal to one-half of that indicated as the resistance period in the fire-endurance test, but not for more than one hour, immediately after which the sample shall be subjected to the impact, erosion, and cooling effects of a fire-hose stream directed first at the middle and then at all parts of the exposed face, changes in direction being made slowly.

(*b*) The fire-hose stream test shall not be required in the case of constructions having a resistance period, indicated in the fire-endurance test, of one-half hour or less.

(*c*) The submitter may elect, with the advice and consent of the testing body, to have the fire-hose stream test made on the sample subjected to the fire-endurance test and immediately following the expiration of the fire-endurance test; provided, that the testing body reserves the right to decide that a fire-hose stream test should be made on a duplicate sample as specified in paragraph (*a*).

(*d*) The stream shall be delivered through 2½-inch hose, discharging through a national standard play pipe of corresponding size equipped with a 1⅛-inch discharge tip of the standard taper smooth-bore pattern without shoulder at the orifice. The water pressure and duration of application shall be as specified in Table 1.

(*c*) The nozzle orifice shall be 20 feet from the center of the exposed surface of the test sample if the nozzle is so located that when directed at the center its axis is normal to the surface of the test sample. If otherwise located, its distance from the center shall be less than 20 feet by an amount equal to 1 foot for each 10° of deviation from the normal.

10. The material or construction shall not be tested until a large proportion of its final strength has been attained and, if it contains free water, until the excess has been given off; this will usually require about 30 days' time under favorable drying conditions. Where this can not be attained within 40 days, artificial drying with air temperature not exceeding 100° F. (38° C.) shall be used.

VI. TESTS OF BEARING WALLS AND PARTITIONS

11. The area exposed to fire shall be not less than 100 square feet, with neither dimension less than 9 feet. The test specimen shall not be restrained on its vertical edges.

12. During the fire-endurance and fire and fire-stream tests the construction shall be loaded in a manner calculated to develop theoretically as nearly as practicable the working stresses contemplated by the design.

13. The test shall not be regarded as successful unless the following conditions are met:

(*a*) The wall or partition shall have sustained the applied load during the fire-endurance test without passage of flame or gases hot enough to ignite cotton waste, for a period equal to that for which classification is desired.

(*b*) The wall or partition shall have sustained the applied load during the fire and fire-stream test as specified in section 9, without passage of flame, stream, or gases hot enough to ignite cotton waste, and after cooling, but within 72 hours after its completion, shall sustain a total load equal to the dead load plus twice the superimposed load specified above.

(*c*) The fire stopping, if any, shall have functioned to prevent passage of fire for a period equal to that for which classification is desired.

(*d*) Transmission of heat through the wall or partition during the fire-endurance test shall not have been such as to raise the temperature on its unexposed surface more than 250° F. (139° C.) above its initial temperature.

APPENDIX D. CENTIGRADE AND FAHRENHEIT CONVERSION TABLE

° C.	0	10	20	30	40	50	60	70	80	90
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
0	32	50	68	86	104	122	140	158	176	194
100	212	230	248	266	284	302	320	338	356	374
200	392	410	428	446	464	482	500	518	536	554
300	572	590	608	626	644	662	680	698	716	734
400	752	770	788	806	824	842	860	878	896	914
500	932	950	968	986	1,004	1,022	1,040	1,058	1,076	1,094
600	1,112	1,130	1,148	1,166	1,184	1,202	1,220	1,338	1,256	1,274
700	1,292	1,310	1,328	1,346	1,364	1,382	1,400	1,418	1,436	1,454
800	1,472	1,490	1,508	1,526	1,544	1,562	1,580	1,598	1,616	1,634
900	1,652	1,670	1,688	1,706	1,724	1,742	1,760	1,778	1,796	1,814
1,000	1,832	1,850	1,868	1,886	1,904	1,922	1,940	1,958	1,976	1,994
1,100	2,012	2,030	2,048	2,066	2,084	2,102	2,120	2,138	2,156	2,174
1,200	2,192	2,210	2,228	2,246	2,264	2,282	2,300	2,318	2,336	2,354
1,300	2,372	2,390	2,408	2,426	2,444	2,462	2,480	2,498	2,516	2,534
1,400	2,552	2,570	2,588	2,606	2,624	2,642	2,660	2,678	2,696	2,714
1,500	2,732	2,750	2,768	2,786	2,804	2,822	2,840	2,858	2,876	2,894
1,600	2,912	2,930	2,948	2,966	2,984	3,002	3,020	3,038	3,056	3,074
1,700	3,092	3,110	3,128	3,146	3,164	3,182	3,200	3,218	3,236	3,254
1,800	3,272	3,290	3,308	3,326	3,344	3,362	3,380	3,398	3,416	3,434
1,900	3,452	3,470	3,488	3,506	3,524	3,542	3,560	3,578	3,596	3,614
2,000	3,632	3,650	3,668	3,686	3,704	3,722	3,740	3,758	3,776	3,794

° C.	° F.	° C.	° F.
1	1.8	6	10.8
2	3.6	7	12.6
3	5.4	8	14.4
4	7.2	9	16.2
5	9.0	10	18.0

° F.	° C.	° F.	° C.	° F.	° C.
1	0.56	7	3.89	13	7.22
2	1.11	8	4.44	14	7.78
3	1.67	9	5.00	15	8.33
4	2.22	10	5.56	16	8.89
5	2.78	11	6.11	17	9.44
6	3.33	12	6.67	18	10.00

EXAMPLES

515° C. = 950° F. + 9° F. = 959° F.
2,039° F. = 1,110° C. + 5° C. = 1,115° C.